Introduction to the Community Earth System Model

Marika Holland
CESM Chief Scientist
Climate and Global Dynamics Division
NCAR Earth Systems Laboratory

Outline

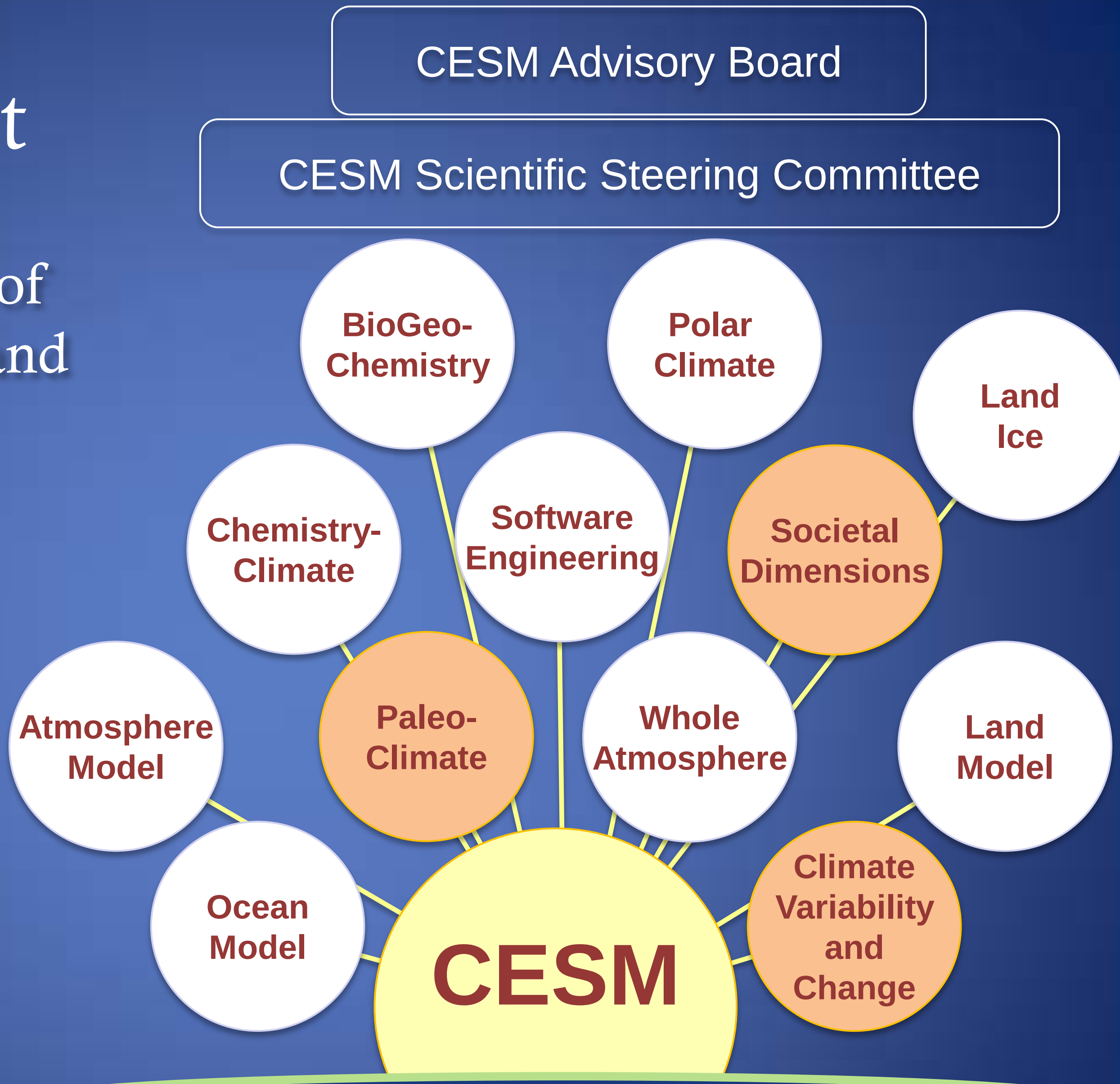
- An Overview of the CESM Model
- Science Highlights
  - CMIP5 Simulations
  - Projected climate from different CESM configurations
- Some New Developments and Directions

Marika Holland
mholland@ucar.edu

CESM Project

Based on 20+ Years of Model development and application

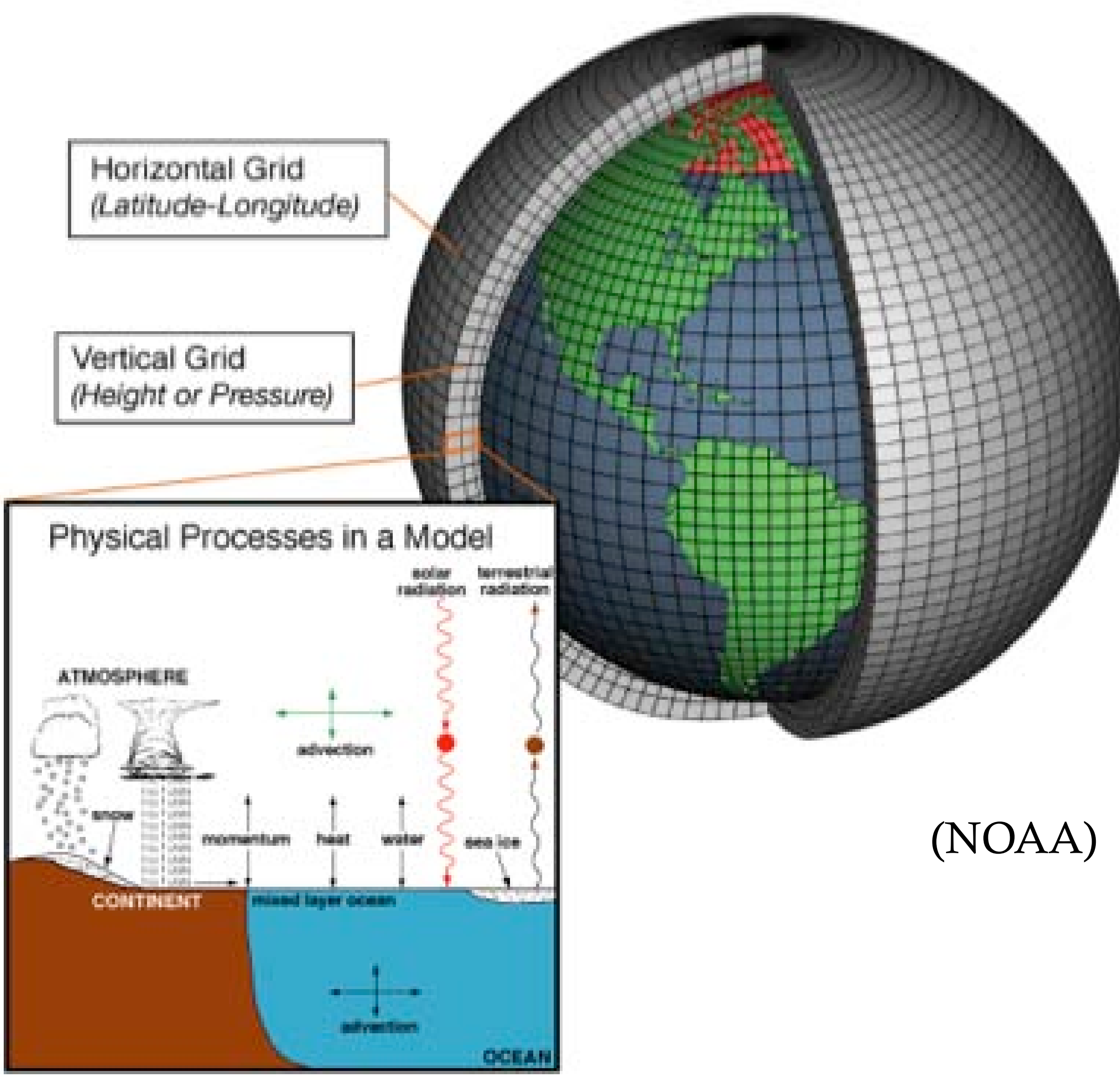
CESM is primarily sponsored by the National Science Foundation and the Department of Energy



http://www.cesm.ucar.edu/management

Marika Holland
mholland@ucar.edu

Community Earth System Model



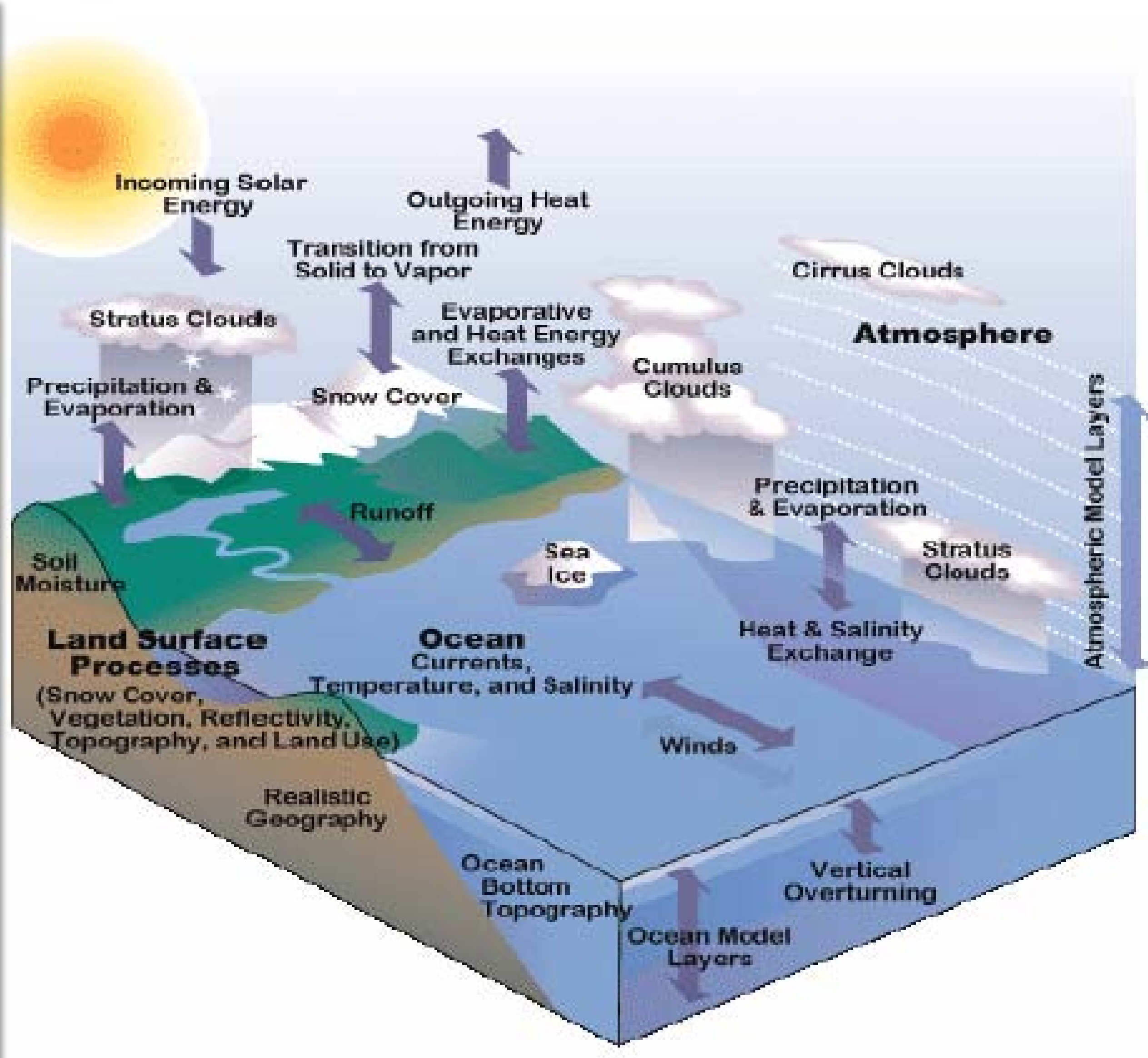
(NOAA)

- Systems of differential equations that describe fluid motion, radiative transfer, etc.
- Planet divided into 3-dimensional grid to solve the equations
- Atmosphere and land traditionally on same horizontal grid
- Similarly for ocean/ice
- Sub-gridscale processes are parameterized

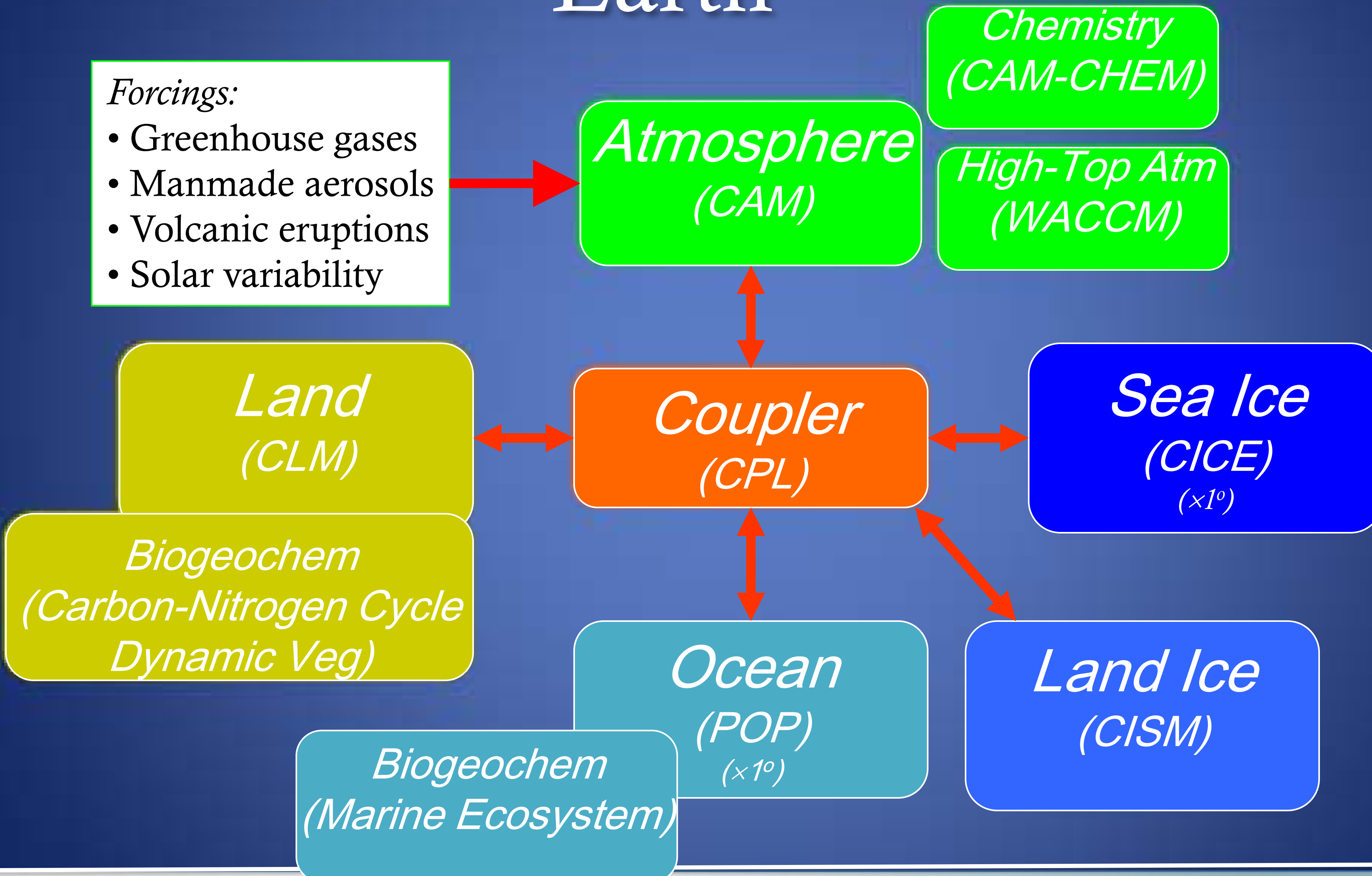
Marika Holland
mholland@ucar.edu

Coupled Climate Models

- Include atmosphere, ocean, land, & sea ice components
- Conservative exchange of heat, water, momentum across components
- Can apply changes in external forcing – solar input, GHGs, volcanic eruptions
- Provide a virtual laboratory for experimentation

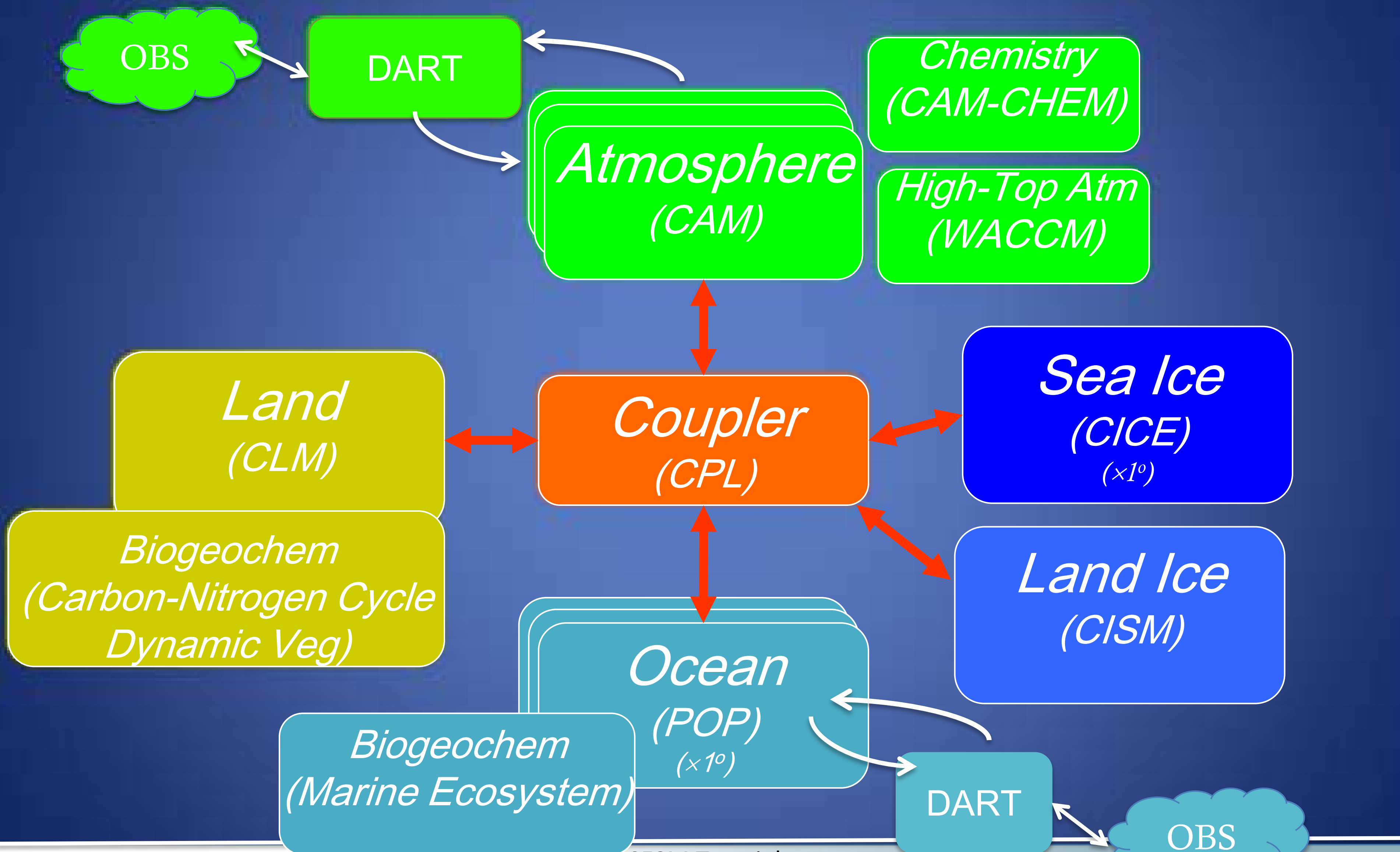


Community ~~Climate~~ Earth System Model



Marika Holland
mholland@ucar.edu

Community Earth System Model



mholland@ucar.edu

Notes on CESM Configurations

- All component models can be active
- All component models can be replaced with "data models"
  - These read in relevant fields for model forcing (for example the datm used in an ocean-only run may read in NCEP for forcing)
  - The ocean model can also be replaced with a slab model
- Numerous options are available within components
  - Can be chosen with namelist options
  - For example different sea ice albedo formulations, etc.
- Increasing number of supported component sets available (including ability to run 20^{th} & 21^{st} century runs)

Marika Holland
mholland@ucar.edu

CESM CMIP5 Simulations

- CCSM4=CAM4, CLM4, CICE4, POP2 (1^{o} resolution for atm/ocn)
  - PI run, 6-20th Century Runs, 6-runs for RCP2.6, RCP4.5, RCP6.0 and RCP8.5
- CESM1-CAM5=CAM5, CLM4, CICE4, POP2 (1^{o} resolution)
  - PI run, 3-20th Century Runs, 3 runs for each RCP
- CESM1-FASTCHEM=CAM-CHEM, CLM4, CICE4, POP2 (1^{o})
  - PI run, 3-20th century runs
- CESM1-BGC=CAM4, CLM4, CICE4, POP2, carbon cycle (1^{o})
  - PI run, 1-20th Century run, 1-RCP4.5, 1-RCP8.5
- CESM1-WACCM=WACCM4, CLM4, CICE4, POP2 (2^{o} atm/1^{o} ocn)
  - PI run, 3-20th century, 3-RCP4.5
- CCSM4_DP (Decadal Prediction) Simulations

Marika Holland
mholland@ucar.edu

Science Highlights

Marika Holland
mholland@ucar.edu

CCSM4/CESM J. Climate Special Collections

- 33 Papers available via AMS early-online release
- Additional papers in various stages of review and preparation
- Document major model components and numerous aspects of simulated variability and change

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CCSM4 Special Collection

Theme Description:

This collection consists of papers analyzing results from the recently completed and released Community Climate System Model, version 4; see [illegible]. The coupled simulations range from runs of past paleoclimates, a long preindustrial control forced by 1850 conditions, an ensemble of 20th century runs, and four ensembles of the future climate using different Representative Concentration Pathways.

CESM1 Special Collection

Theme Description:

The second part of this collection has papers analyzing results from the recently completed and released Community Earth System Model, version 1; see [illegible]. The new components that are available which turn it into an Earth System Model are: carbon cycle modules in the land, ocean, and atmosphere components; an interactive chemistry component in the atmosphere; a version of the atmosphere that reaches into the upper stratosphere, called WACCM; and a completely new land ice component. In addition, an updated version of the atmosphere component, CAM5, is available, which uses several new parameterizations, and can simulate the indirect effects of aerosols.

The CCSM4/CESM1 Special Collection organizers are:

Peter Gent, Past Chairman of the CCSM Project SSC ([illegible])
Jim Hurrell, Chairman of the CCSM Project SSC ([illegible])

Abstracts for all AMS articles are available to everyone, as is the full text of Bulletin articles. Access to full-text HTML and PDF articles in the technical journals is limited to paid subscribers.

denotes open access content.

Semyon A. Grodsky, James A. Carton, Sumant Nigam, Yuko M. Okumura, **Tropical Atlantic Biases in CCSM4.** *Journal of Climate*, early online release.
Abstract · PDF (1250 KB)

Gerald A. Meehl, Warren M. Washington, Julie M. Arblaster, Aixue Hu, Haiyan Teng, Claudia Tebaldi, Ben Sanderson, Jean-Francois Lamarque, Andrew Conley, Warren G. Strand, James B. White III. **Climate system response to external forcings and climate change projections in CCSM4.** *Journal of Climate*, early online release.
Abstract · PDF (9088 KB)

C. M. Bitz, K. M. Shell, P. R. Gent, D. Bailey, G. Danabasoglu, K. C. Armour, M. M. Holland, J. T. Kiehl, **Climate Sensitivity of the Community Climate System Model Version 4.** *Journal of Climate*, early online release.
Abstract · PDF (2920 KB)

Keith Oleson, **Contrasts between urban and rural climate in CCSM4 CMIP5 climate change scenarios.** *Journal of Climate*, early online release.
Abstract · PDF (4067 KB)

Alexandra Jahn, Kara Sterling, Marika M. Holland, Jennifer E. Kay, James A. Maslanik, Cecilia M. Bitz, David A. Bailey, Julienne Stroeve, Elizabeth C. Hunke, William H. Lipscomb, Daniel A.

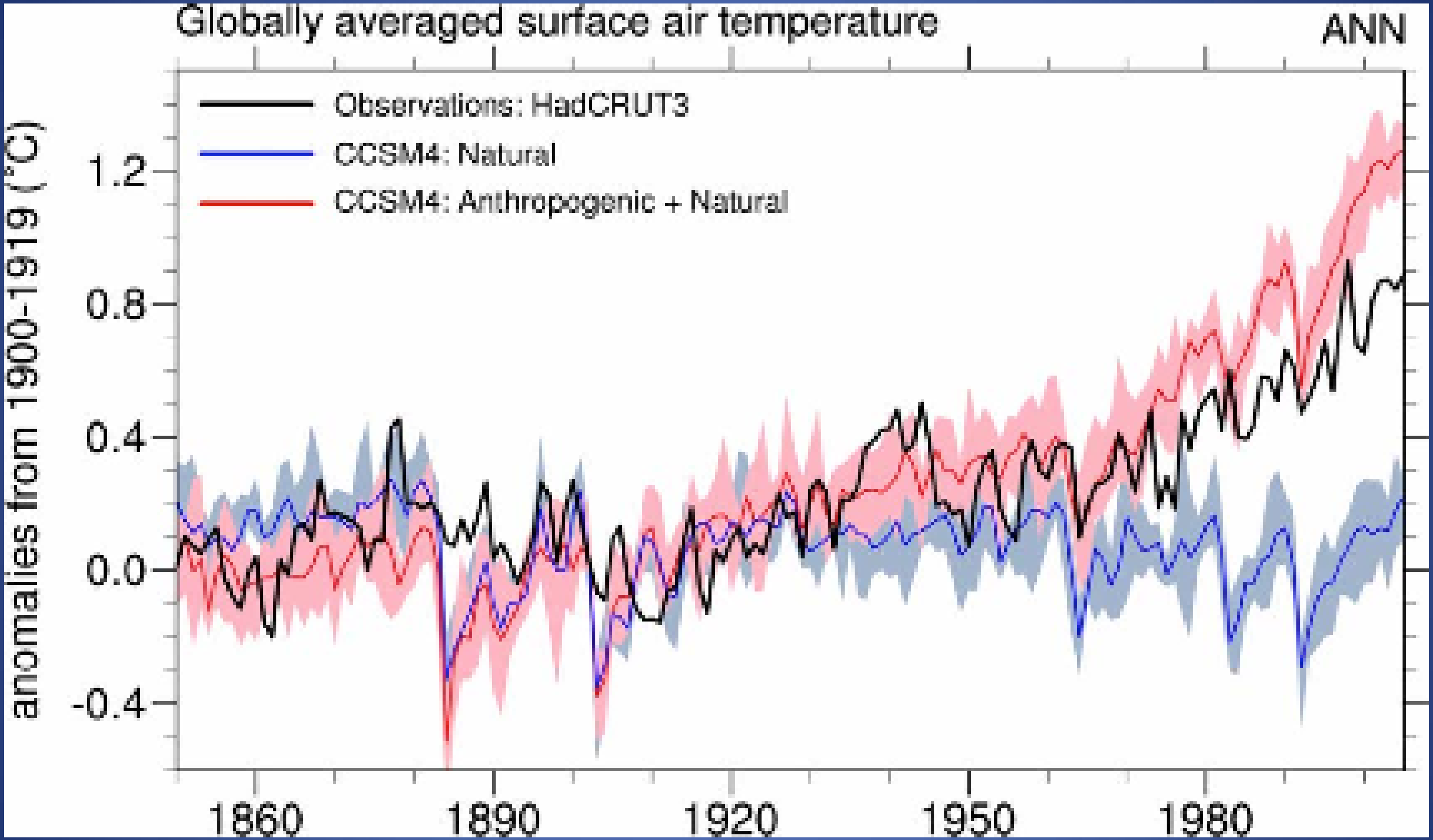
http://journals.ametsoc.org/page/CCSM4/CESM1

Science Highlights: Climate Change and Feedbacks

CMIP5 Runs for:
CCSM4
CESM1-CAM5
CESM1-CISM
CESM1-BGC
CCSM4-DP

Marika Holland
mholland@ucar.edu

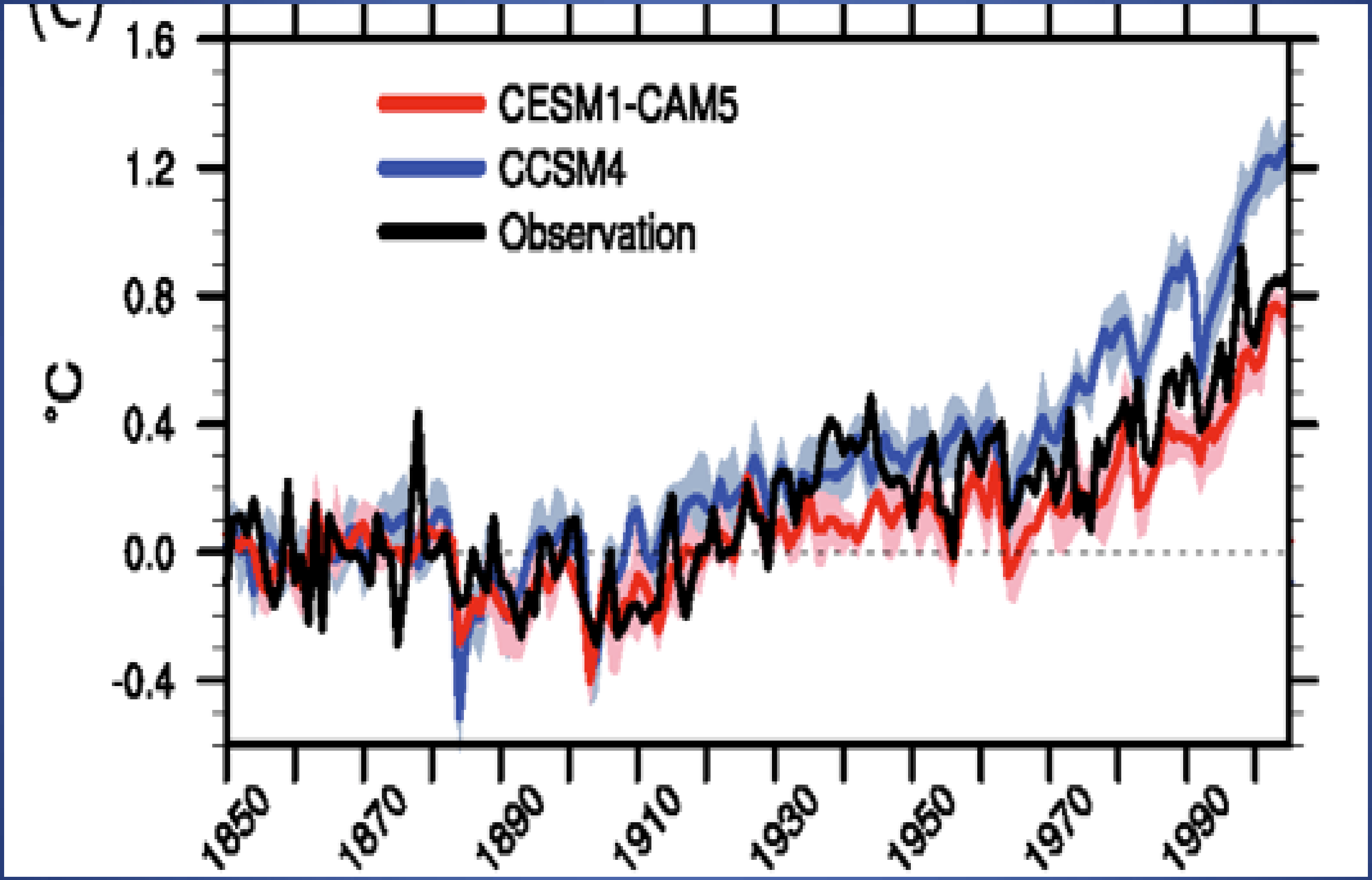
CCSM4 20th Century Change



(From Meehl et al., 2012)

Marika Holland
mholland@ucar.edu

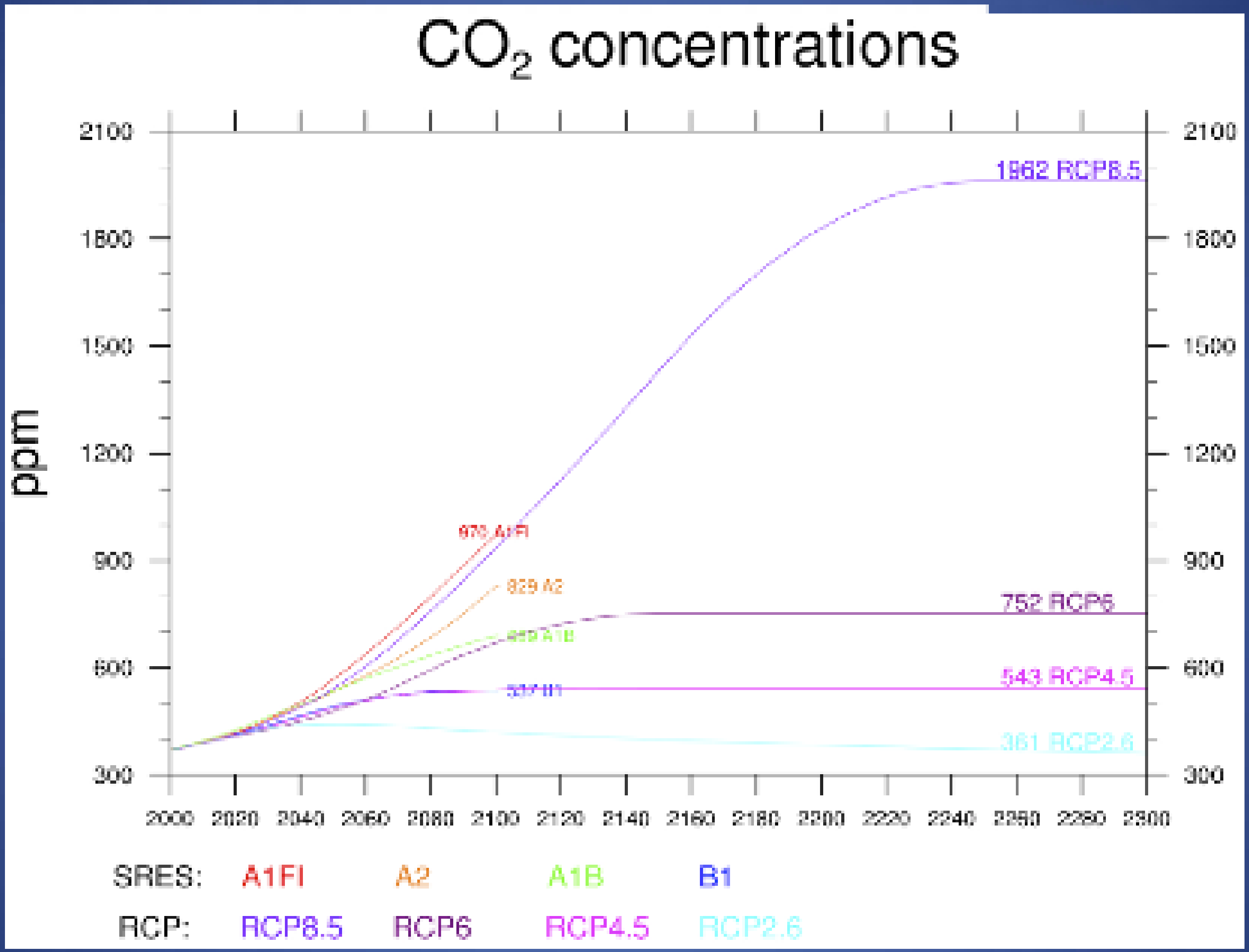
CESM1-CAM5 20th Century Change



Hurrell et al., in prep

Marika Holland
mholland@ucar.edu

Projected 21st Century Change



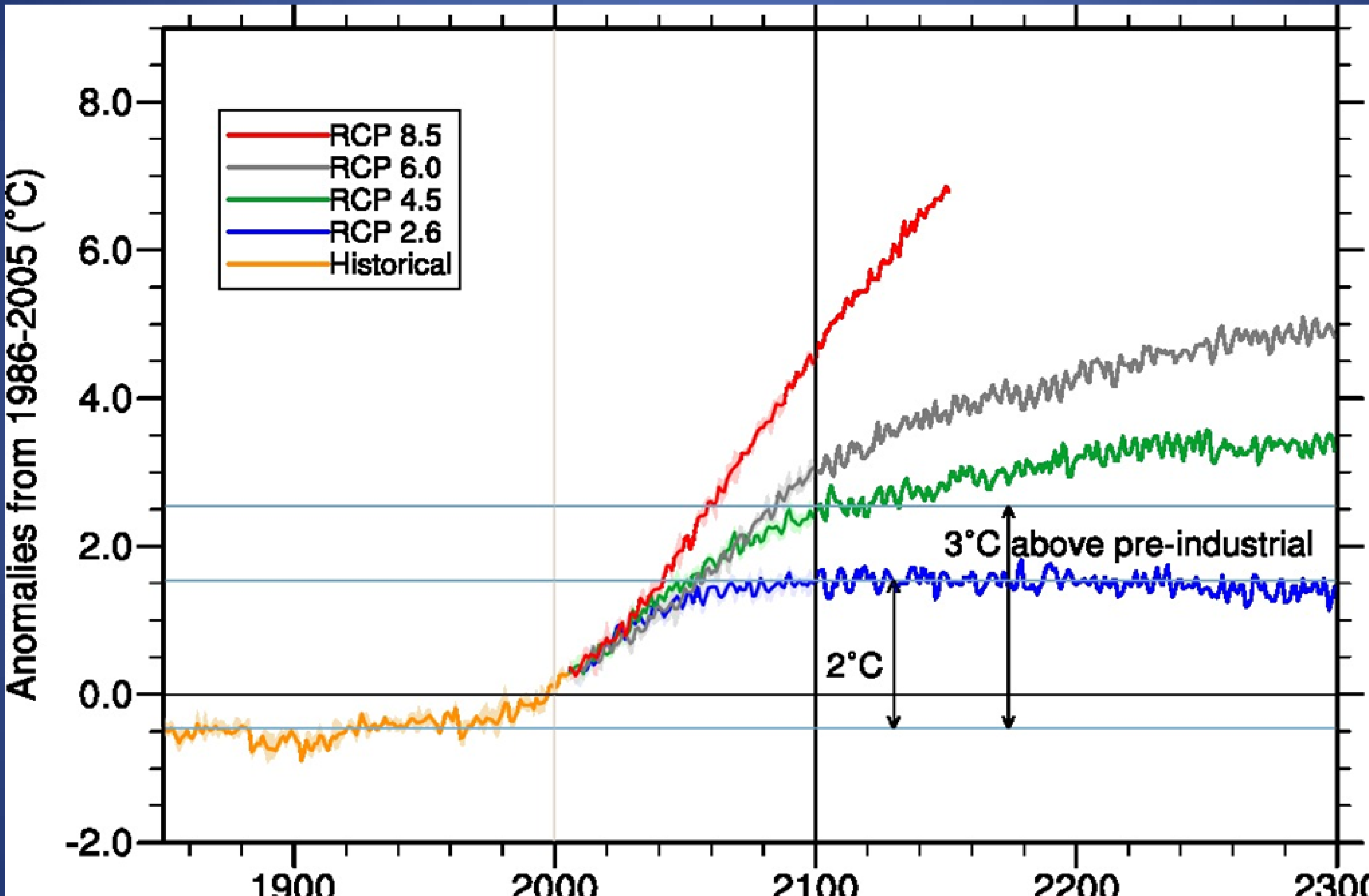
(From Meehl et al., 2012)

Marika Holland
mholland@ucar.edu

Global Surface Air Temperature Change

CESM1-CAM5

CCSM4

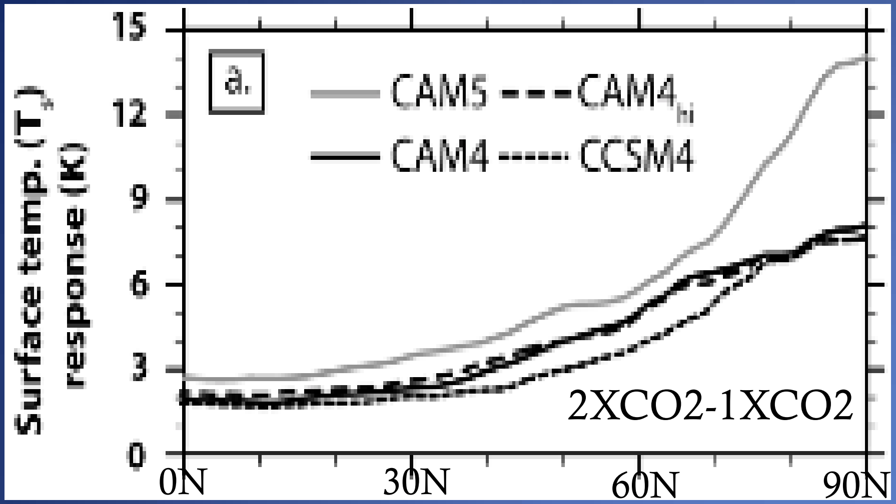


(Meehl, G.A., W.M. Washington, J.M. Arblaster, A. Hu, H. Teng, C. Tebaldi, B. Sanderson, J.F. Lamarque, A. Conley, and W.G. Strand, 2012: Climate change projections in CESM1/CAM5. *J. Climate*, in preparation).

Meehl et al. 2012

Marika Holland
mholland@ucar.edu

Climate Sensitivity



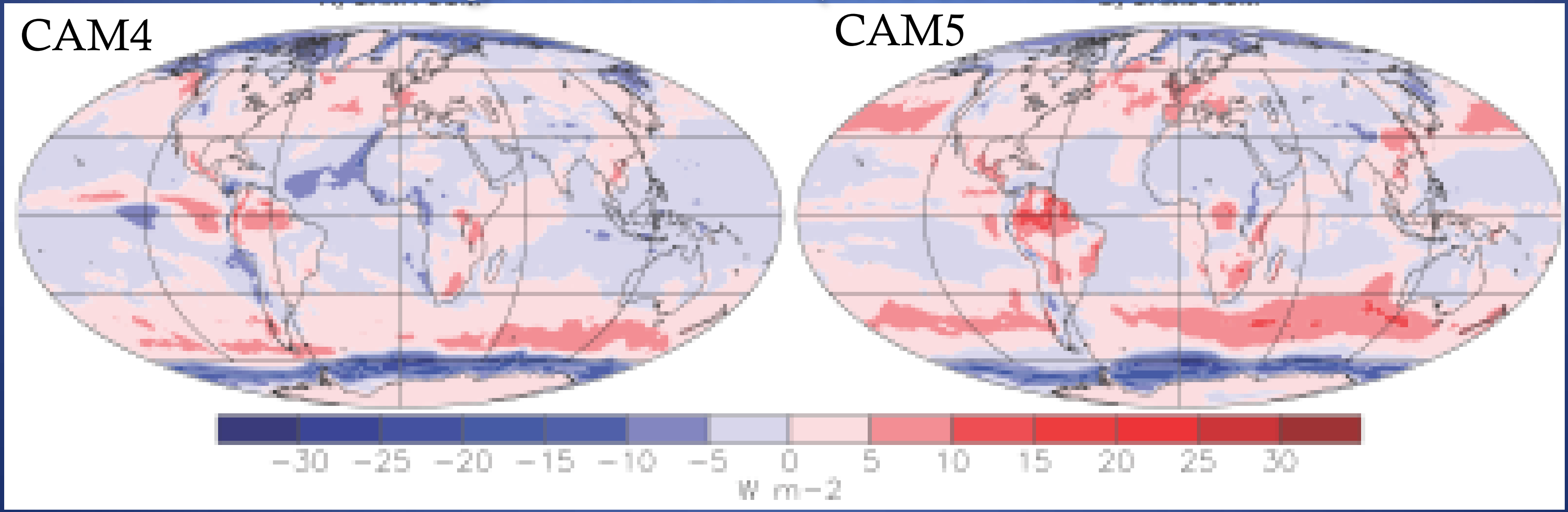
Surface Temperature Change for doubled CO2

3.2K in CAM4

4.0K in CAM5

Feedback analysis (Gettleman et al, 2012) suggests considerably different cloud feedbacks – particularly in mid-latitudes – are largely responsible

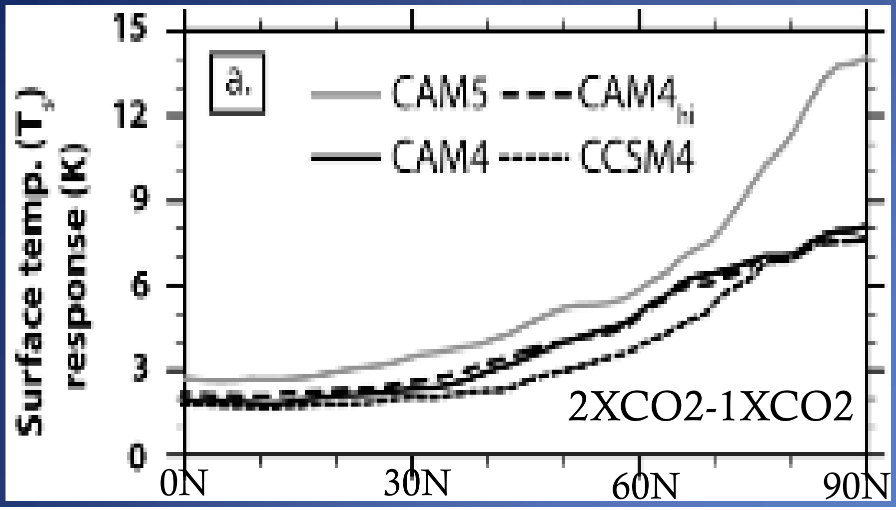
Change in total CRF (2XCO2-1XCO2)

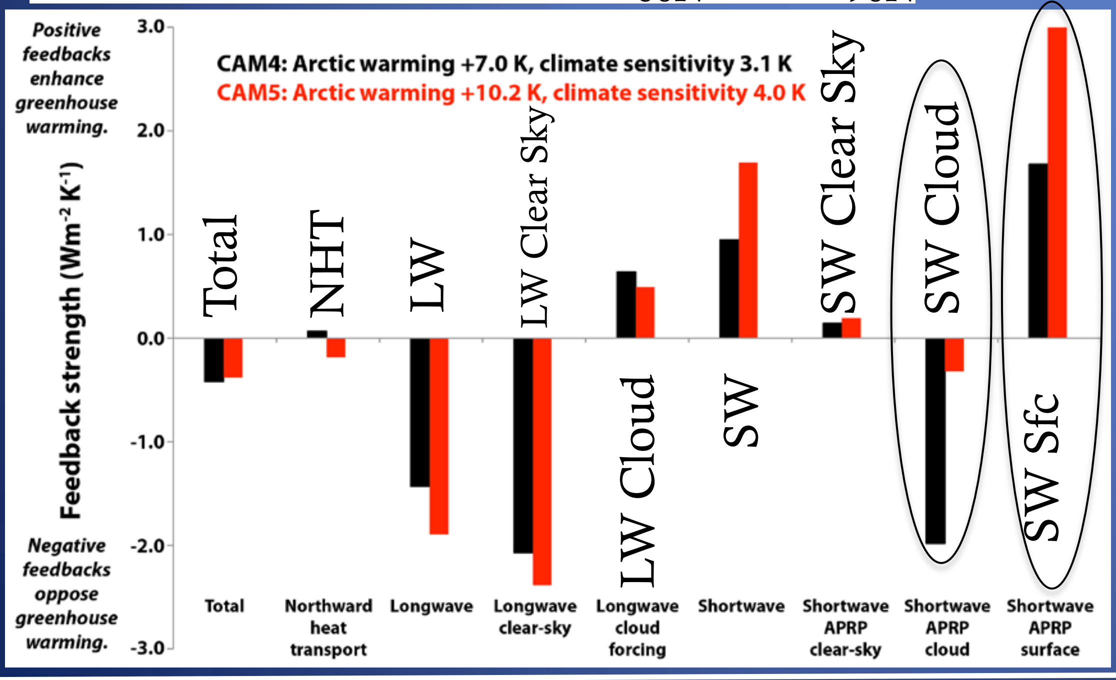


Bitz et al., 2012; Gettelman et al., 2012; Kay et al., 2012

Marika Holland
mholland@ucar.edu

Climate Sensitivity





CAM5 also has considerably higher Arctic amplification

Feedback Analysis (Kay et al) suggests this results from:

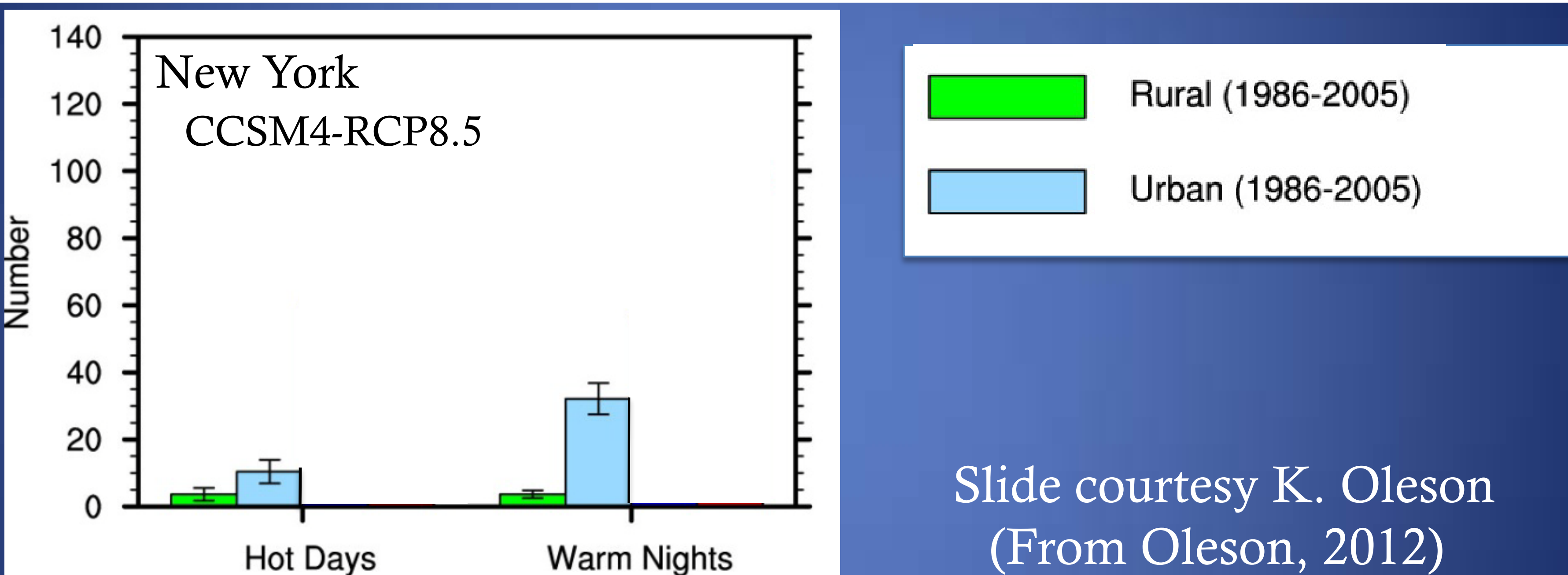
- Less negative SW Cloud Feedbacks
- More positive surface albedo feedback

Gettelman et al., 2012; Kay et al., 2012

Marika Holland
mholland@ucar.edu

Changing Extremes:
Changes in hot days and warm nights

Hot days (warm nights) – Number of days per year that daily TMAX (TMIN) exceeds 99th percentile of present day Rural daily TMAX (TMIN)



Slide courtesy K. Oleson (From Oleson, 2012)

Present-day climate

Cities have more hot days and warm nights than rural land

Marika Holland
mholland@ucar.edu

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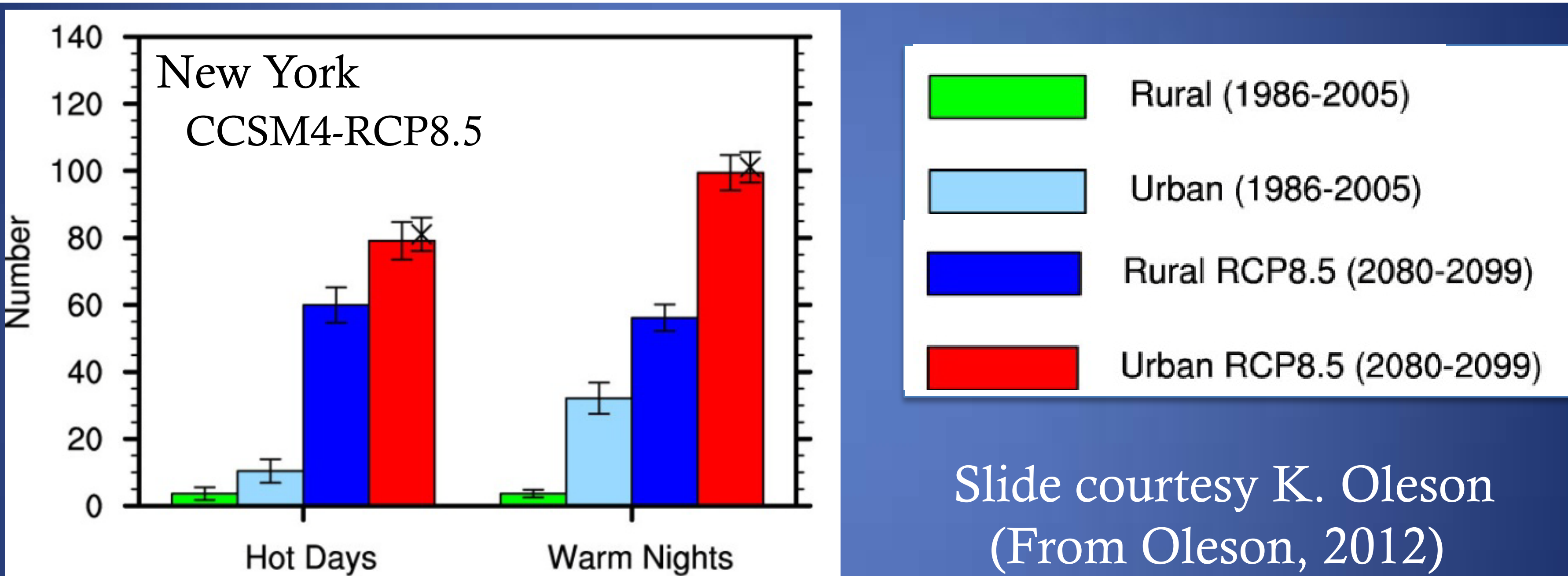


Slide courtesy K. Oleson (From Oleson, 2012)

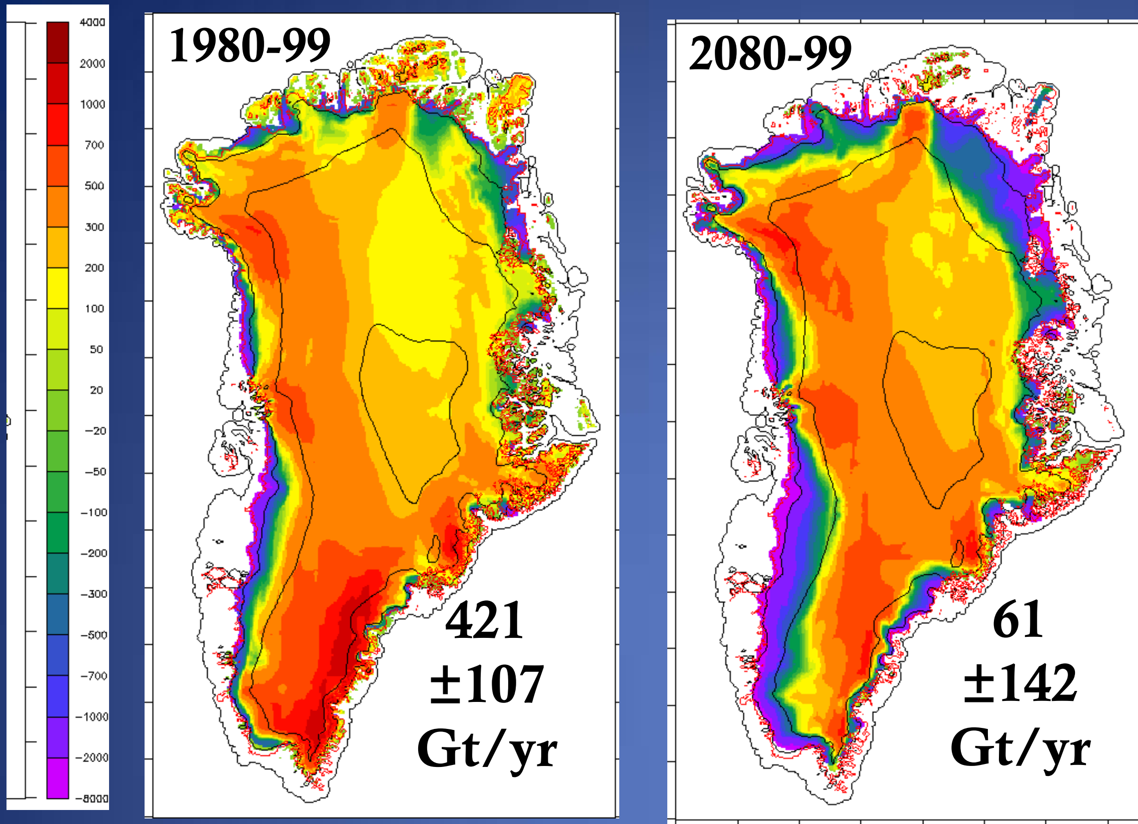
Present-day climate

Cities have more hot days and warm nights than rural land

21st century climate change

Cities increase more in hot days and warm nights than does rural land

Marika Holland
mholland@ucar.edu



CESM1-CISM

Changing Ice Sheet Conditions

Community Ice Sheet Model (CISM)

Simulated Greenland surface mass balance (red = net growth purple = net melting)

- Fully coupled CMIP5 simulations (preindustrial, 20th century, RCP8.5) with Greenland ice sheet model are completed
  - 20th century surface mass balance (SMB) agrees well with regional models
  - SMB approaches zero by late 21st century, implying long-term instability
- Ran 100-member spin-up ensemble to optimize Greenland ice sheet parameters for modern climate

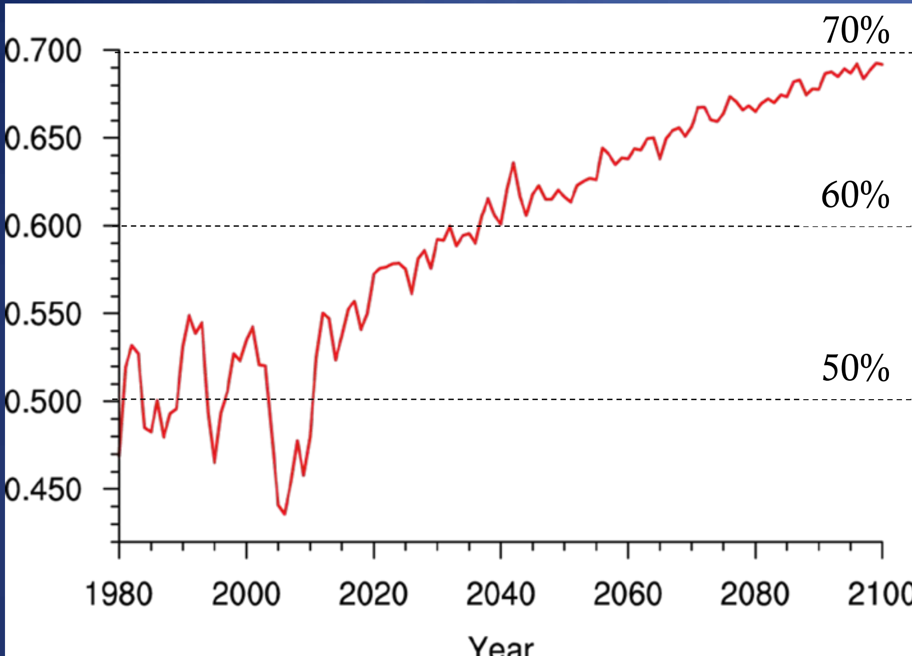
Slide courtesy of Bill Lipscomb

Marika Holland
mholland@ucar.edu

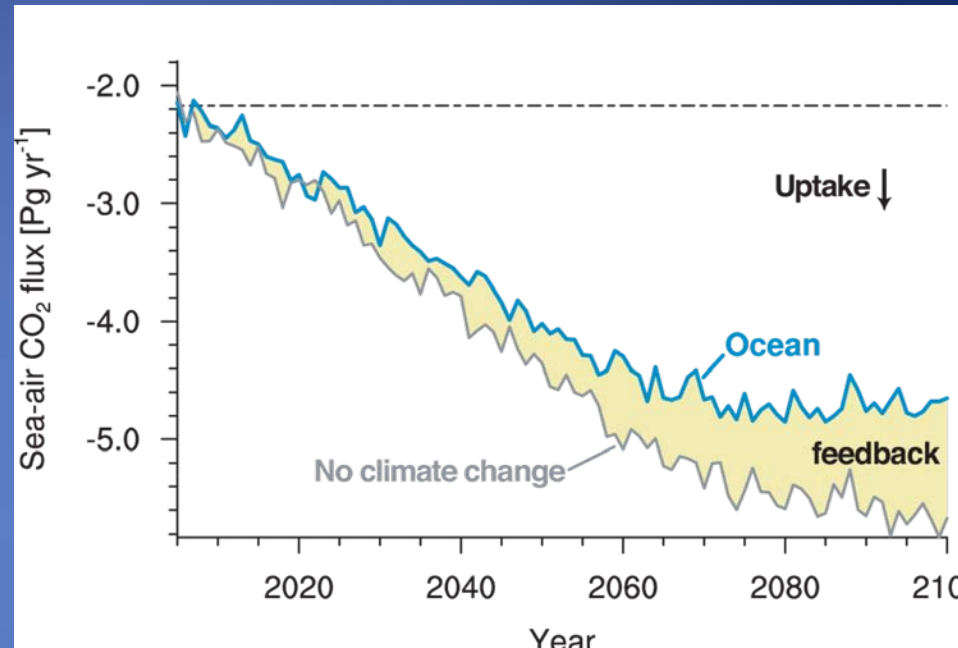
CESM1-BGC: 21st Century carbon cycle

Prognostic global carbon budget

Airborne CO2 Fraction



Ocean sink: climate-carbon feedback

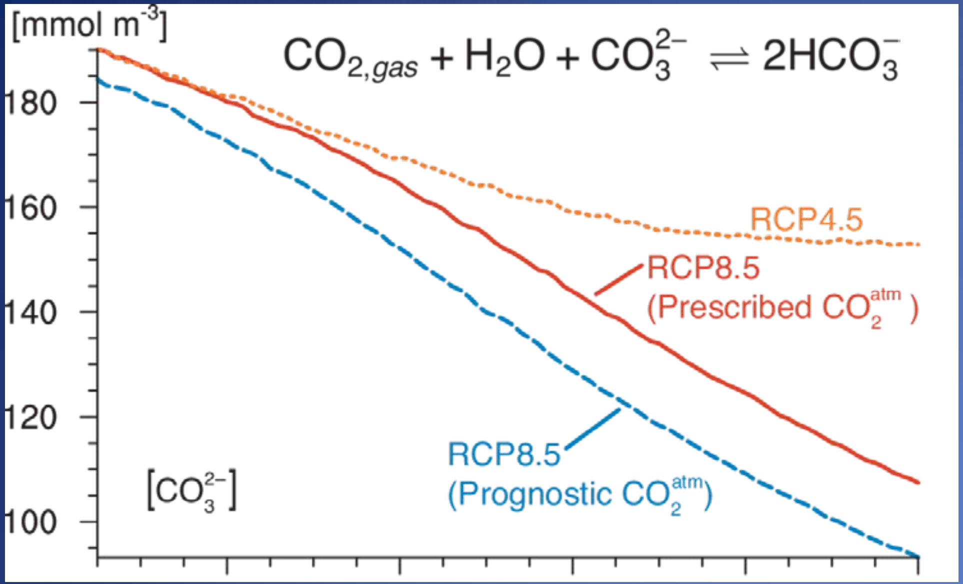


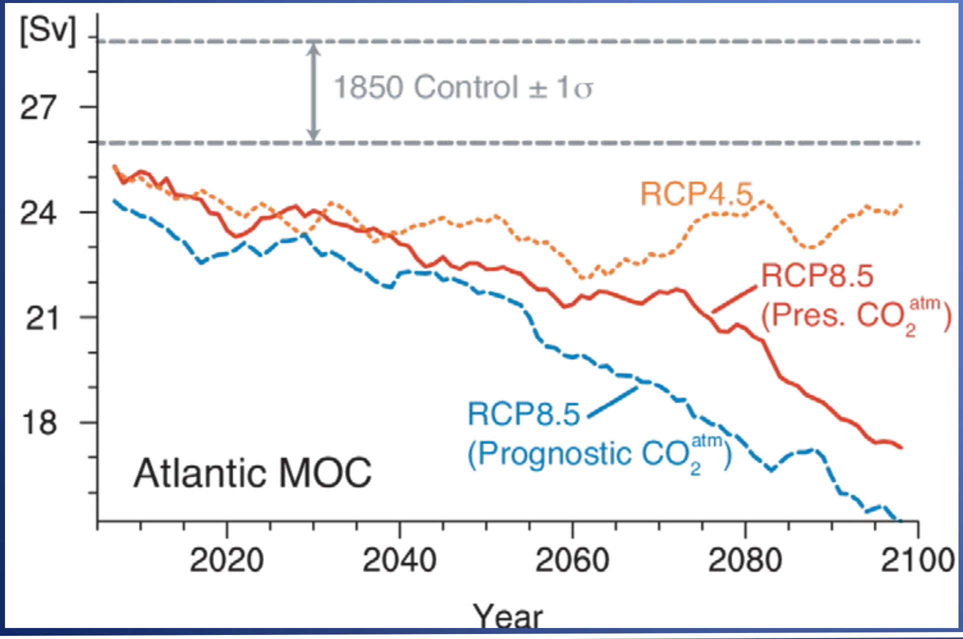
- Emissions specified, atmospheric CO_2 is modeled as a function of surface fluxes;
- Ocean carbon sink stabilizes late-21st century—in part a result of climate-carbon feedback;
- Airborne fraction increases.

Slides courtesy of Matt Long

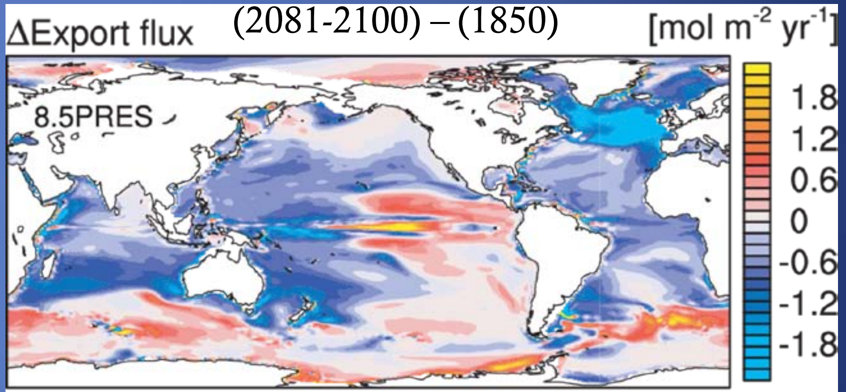
Marika Holland
mholland@ucar.edu

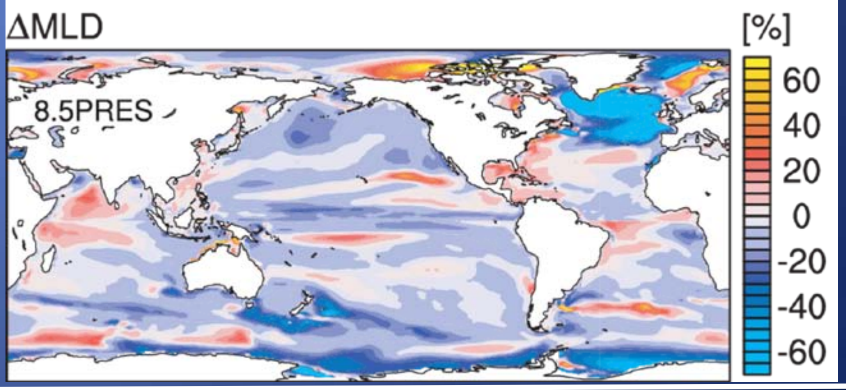
CESM1-BGC: 21st Century Ocean carbon sink stabilization





- Ocean Chemistry - Consumption of carbonate ion reduces buffer capacity;
- Ocean Circulation - MOC slow down and stratification inhibit ventilation;
- Ocean Biology - Nutrient limitation drives reductions in biological export

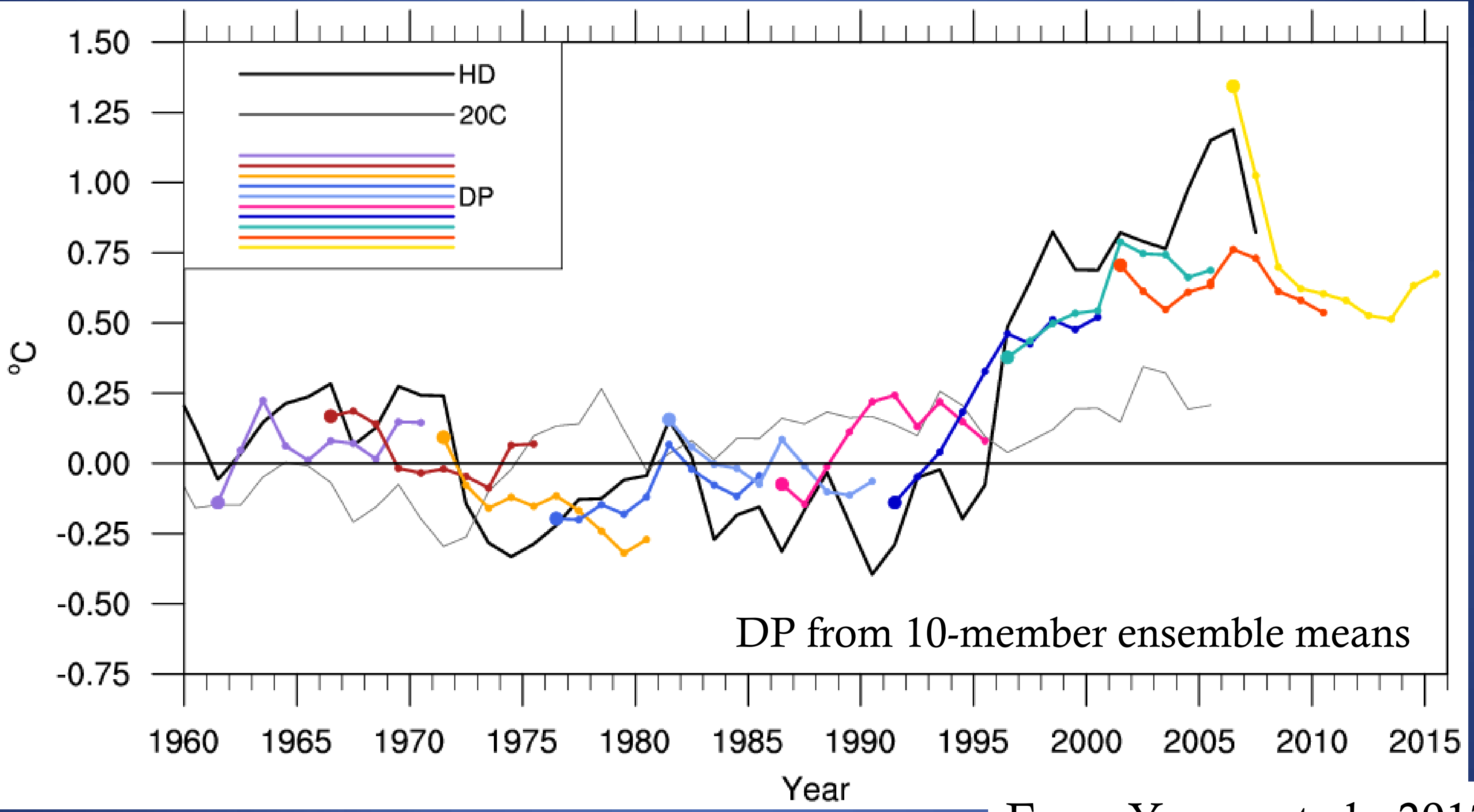




Marika Holland
mholland@ucar.edu

Decadal Prediction

275-m HEAT CONTENT ANOMALY IN SPG BOX



From Yeager et al., 2012

After drift correction, there is skill in reproducing historical changes in the SPG

Marika Holland
mholland@ucar.edu

Where We Are Heading

Higher Resolutions with New Science Applications

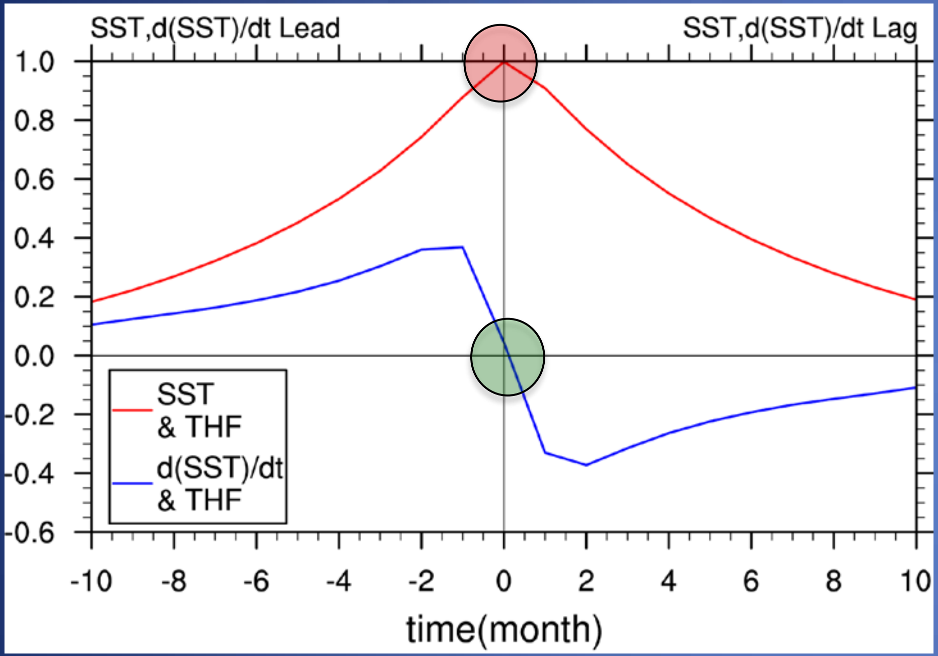
New Model Capabilities

Improved Earth System Processes

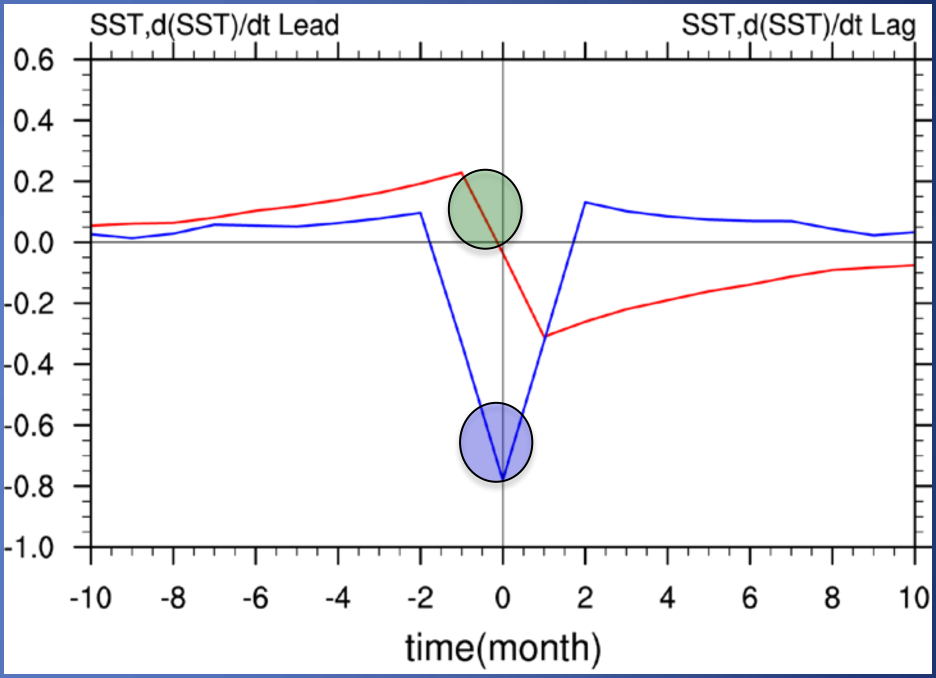
Marika Holland
mholland@ucar.edu

Higher Resolution Simulations Enabling Studies on Ocean-Atmosphere Scale Interactions

Ocean Weather



Atmosphere Weather



SST & SHF

d(SST)/dt & SHF

Courtesy of Frank Bryan

Marika Holland
mholland@ucar.edu

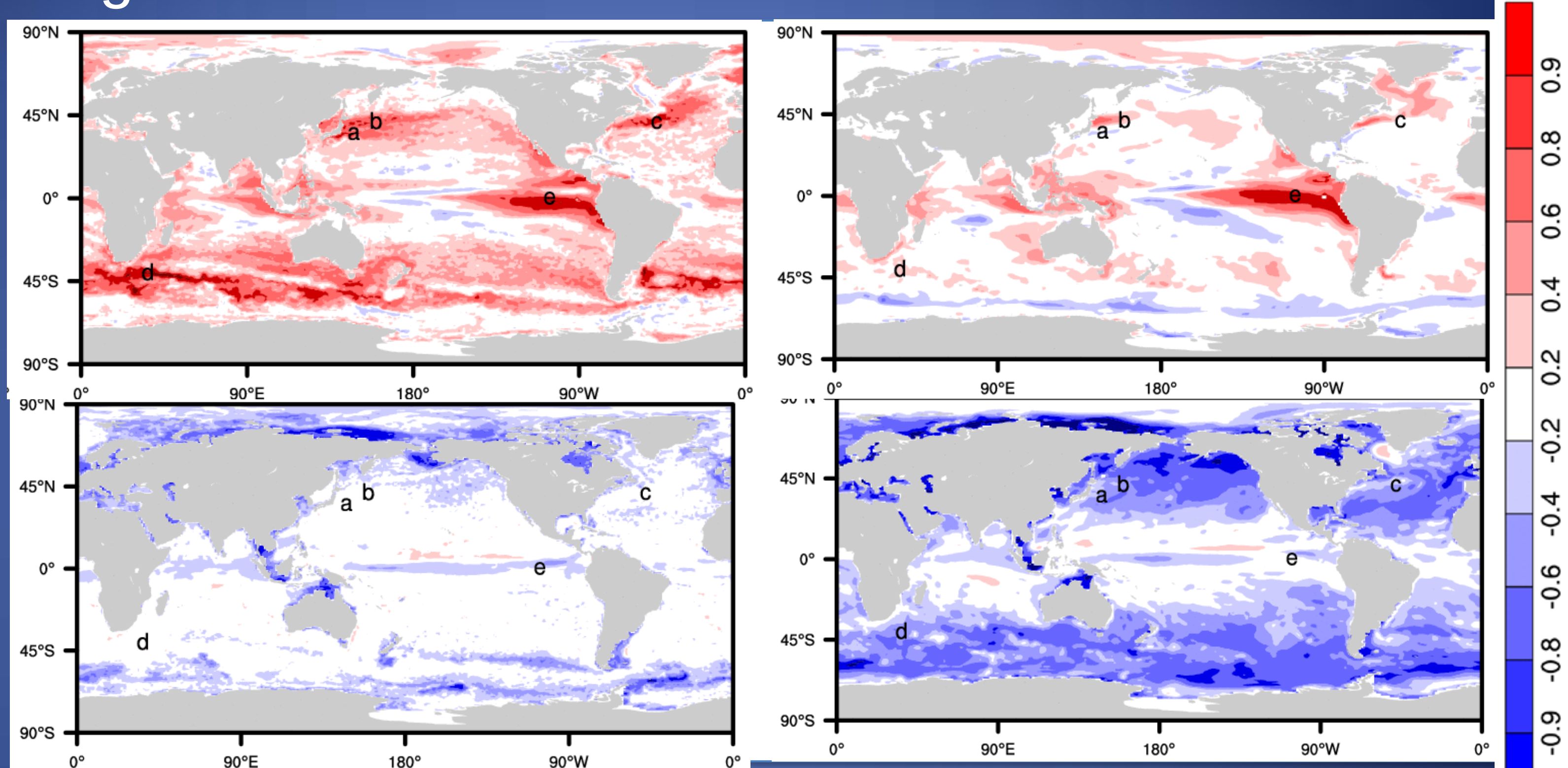
Ocean-Atmosphere Scale Interactions

Correlation

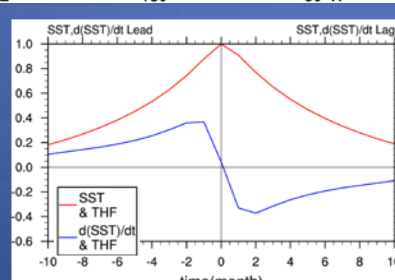
High Resolution | Low Resolution

SST & SHF

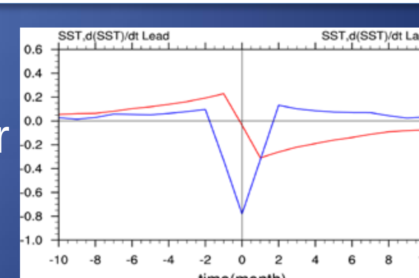
d(SST)/dt & SHF



Ocean Weather



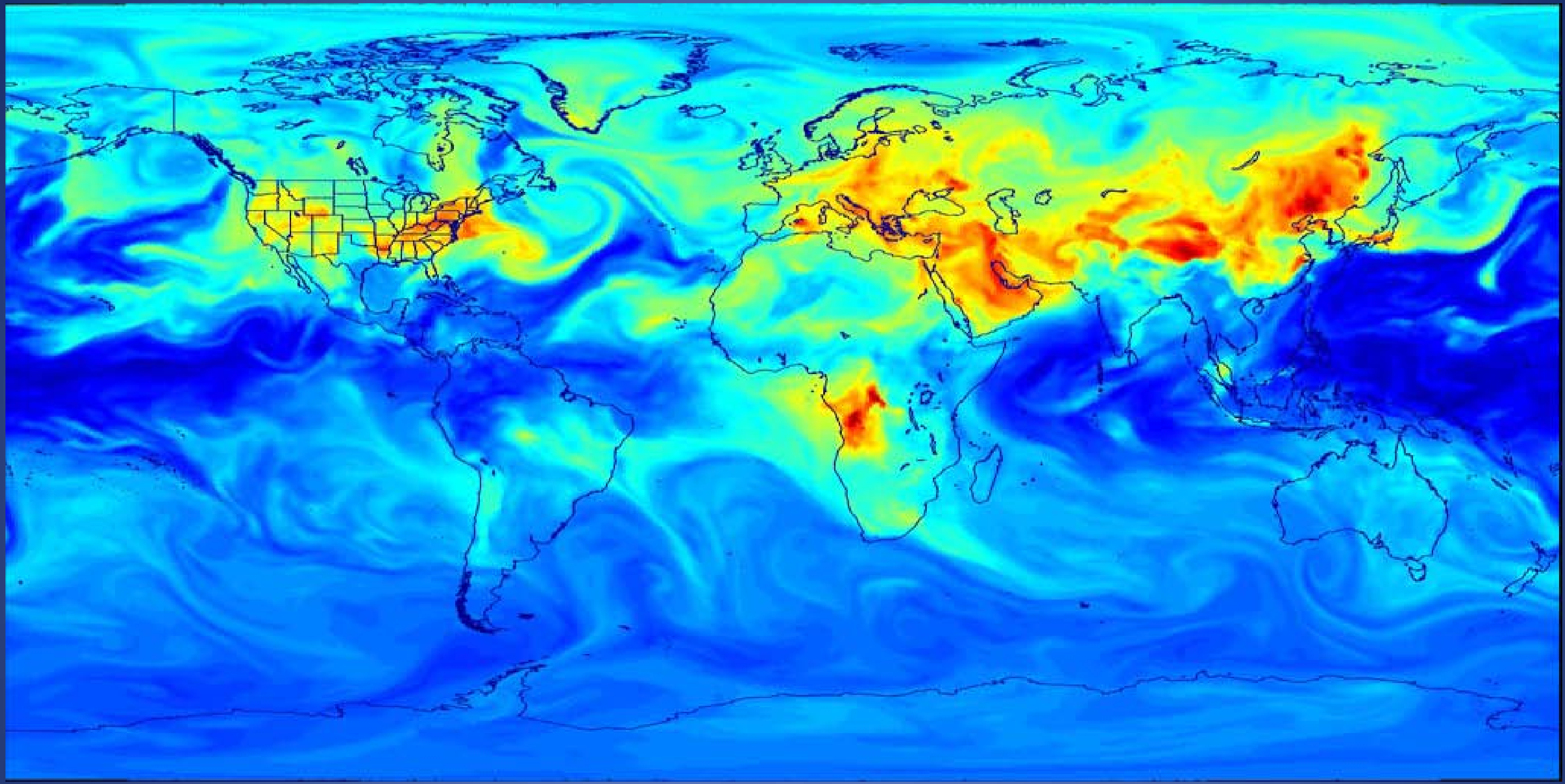
Atm Weather



Courtesy of Frank Bryan

Marika Holland
mholland@ucar.edu

Atmospheric Chemistry



Snapshot of Simulated Ozone Concentration in Lowest 2km

High-resolution (~0.5 degree) simulations driven by GEOS-5 meteorology

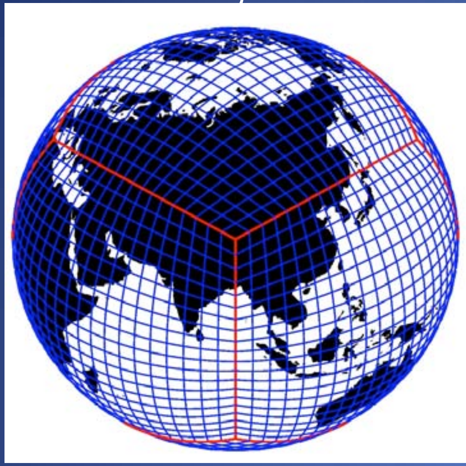
Slide courtesy of Jean-Francois Lamarque
Simulation by Louisa Emmons

Marika Holland
mholland@ucar.edu

High Resolution: New Dynamical Cores

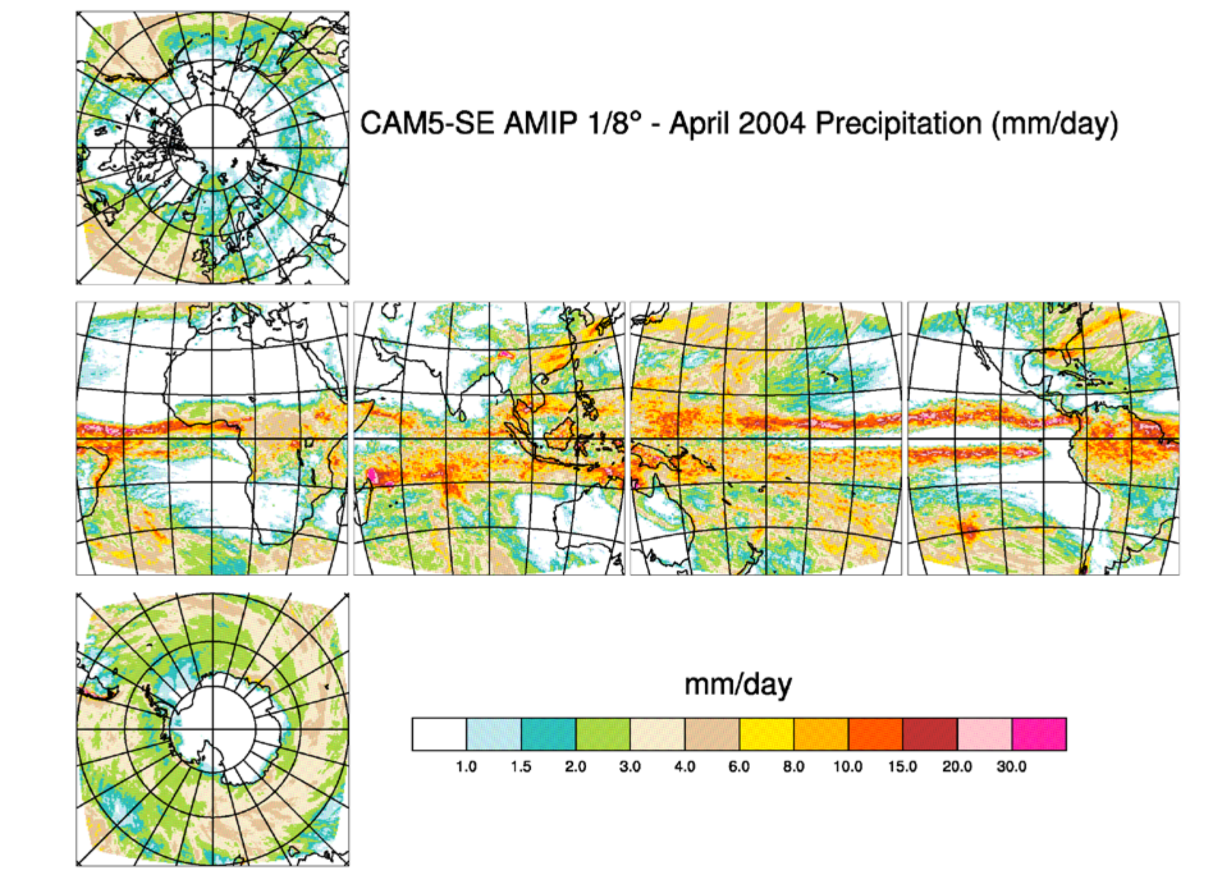
CAM5-Spectral Element on Cubed Sphere Grid

Cubed Sphere



Regular lat-lon

SE Dynamical Core – More conservative and less diffusive than FV. Scales efficiently to many processors.



Slide courtesy of Rich Neale

Marika Holland
mholland@ucar.edu

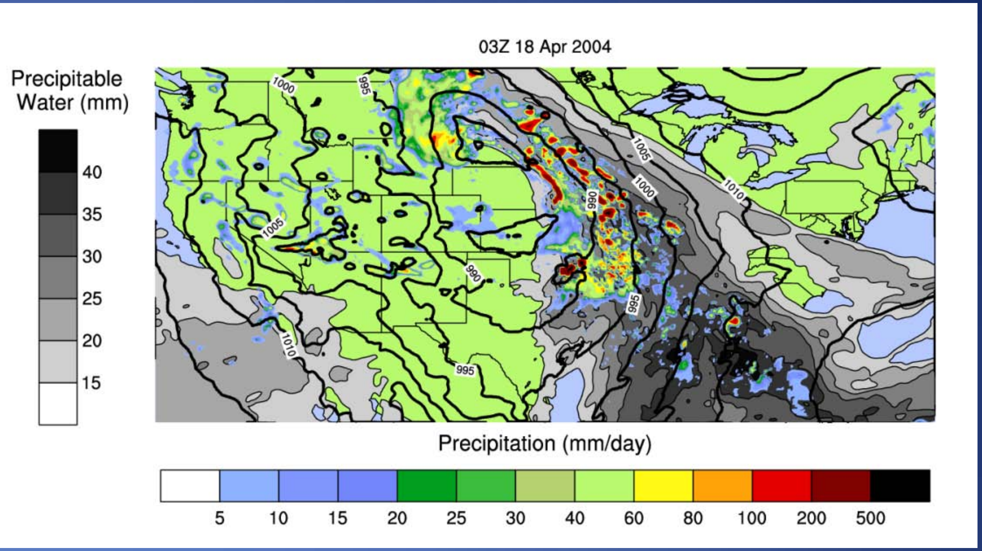
High Resolution: New Dynamical Cores

CAM5-Spectral Element on Cubed Sphere Grid

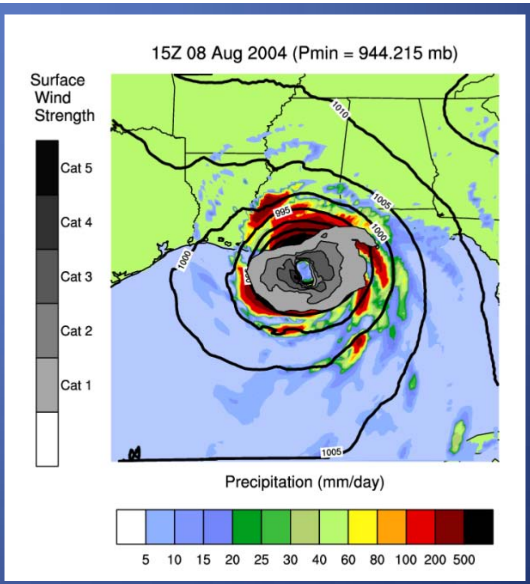
Cubed Sphere

Regular lat-lon

Mid-west Spring time propagating systems



Tropical Cyclones



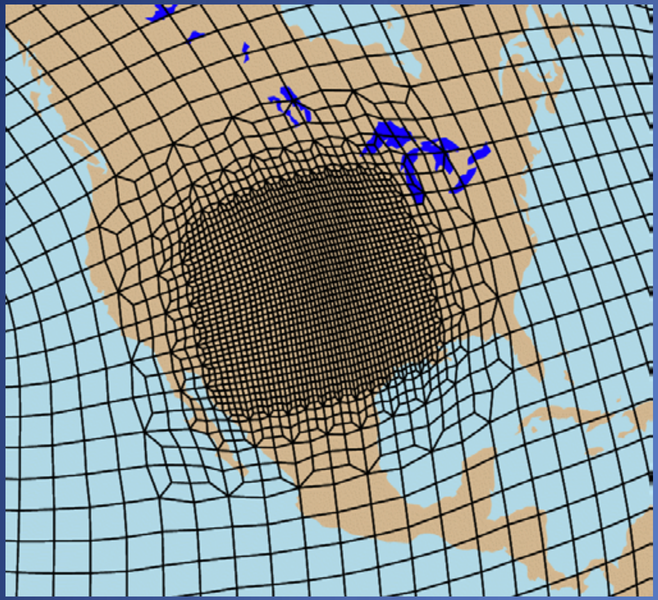
12-km CAM-SE Run

Slide courtesy of Rich Neale

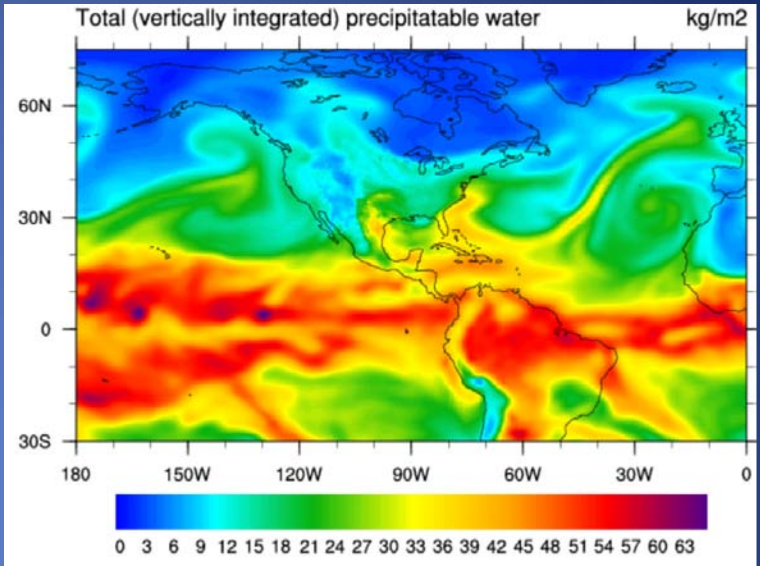
Marika Holland
mholland@ucar.edu

CESM1(CAM5-SE): Regional Refinement

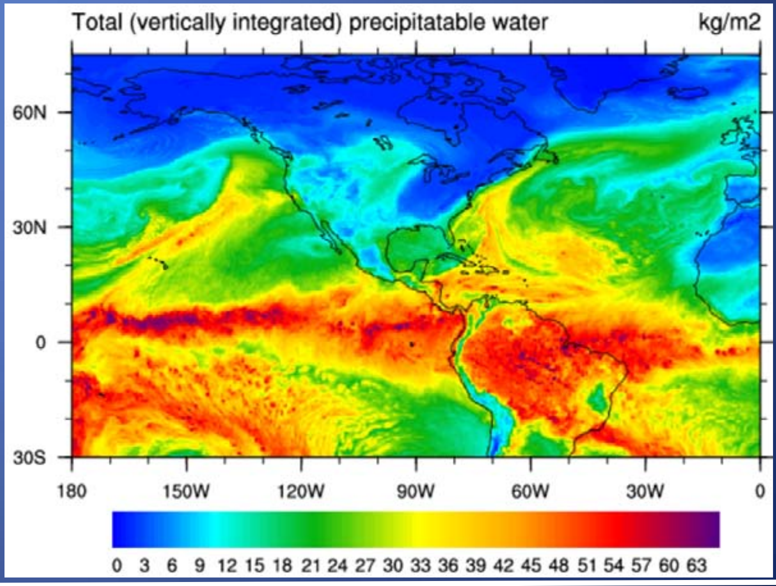
Avoiding Downscaling BUT Implications for resolution dependence



1° to 1/8° Over USA



Global 1/8°



- ✓ 3 levels (steps) of refinement
- ✓ CAM5-SE AMIP simulations
- ✓ Regional refinement should reproduce statistics of global high-res equivalent
- ✓ Land can run on same grid
- ✓ Calibration testbed

Slide courtesy of Mark Taylor

Marika Holland
mholland@ucar.edu

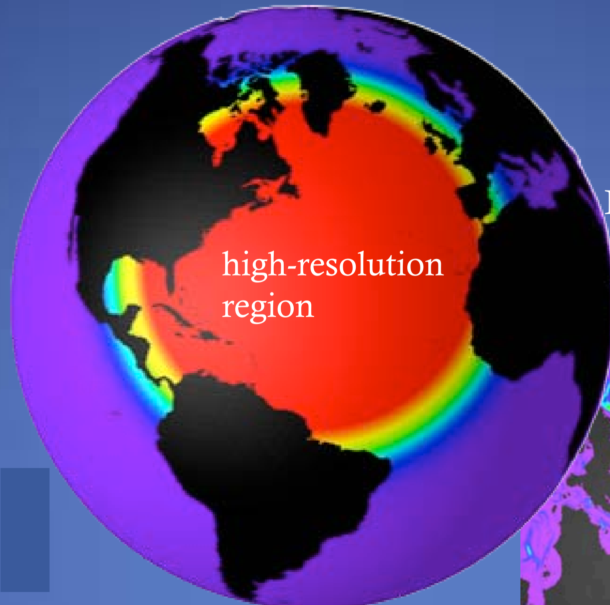
MPAS
Model for Prediction Across Scales

Building a Global, Multi-Scale Ocean Model

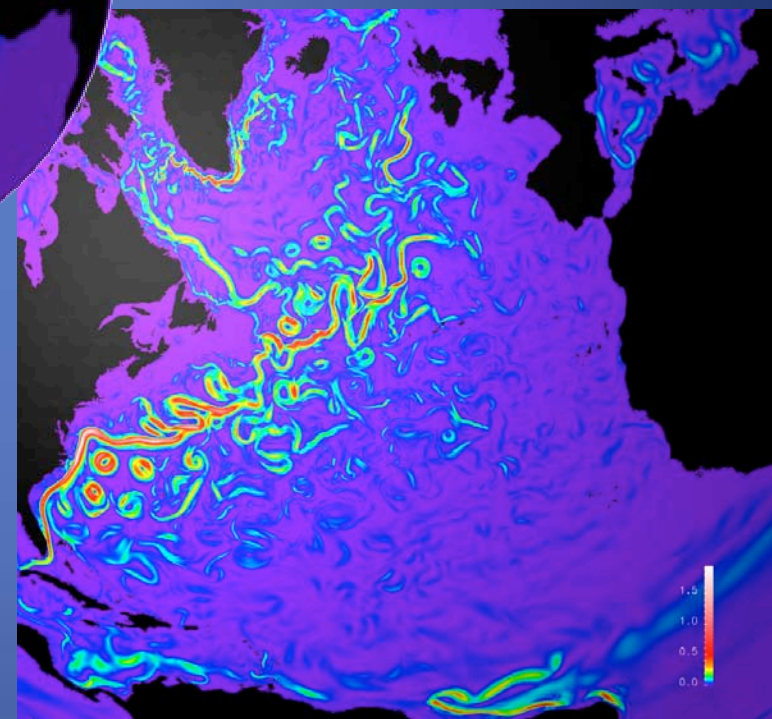
MPAS supports both quasi-uniform and variable resolution meshing of the sphere.

MPAS development is a partnership between NCAR and LANL.

The MPAS ocean (MPAS-O) model will be coupled into the CESM over the next year.



Below: Snapshot of kinetic energy from a global ocean simulation with 7.5 km resolution in the North Atlantic. The rest of the global ocean is resolved with a 38 km mesh.



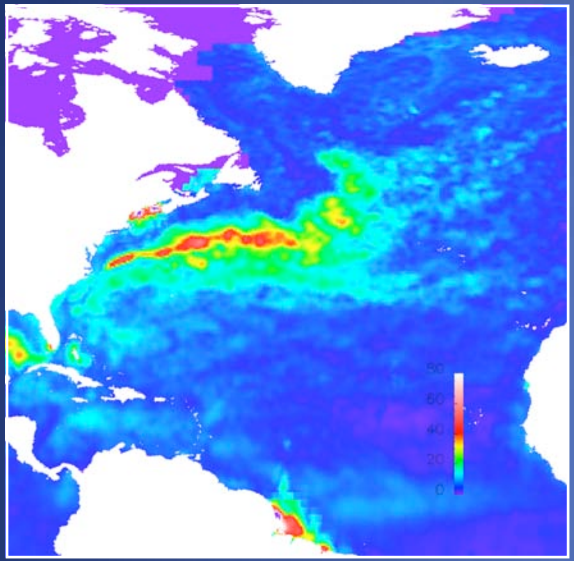
Slide courtesy of Todd Ringler

Marika Holland
mholland@ucar.edu

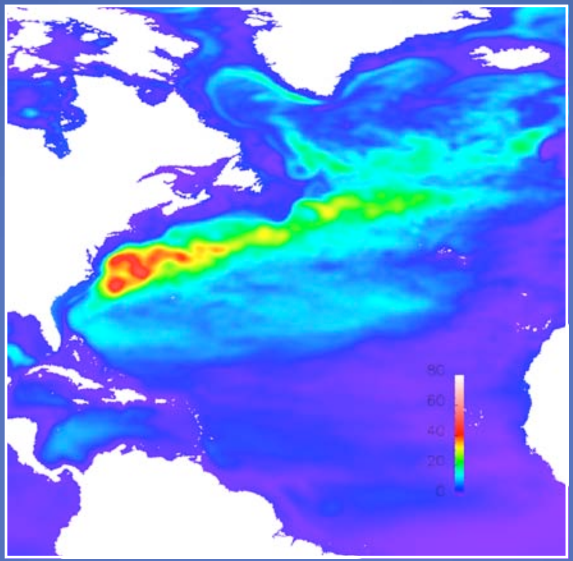
Simulating Mesoscale Eddies on a Variable Resolution Mesh.

MPAS
Model for Prediction Across Scales

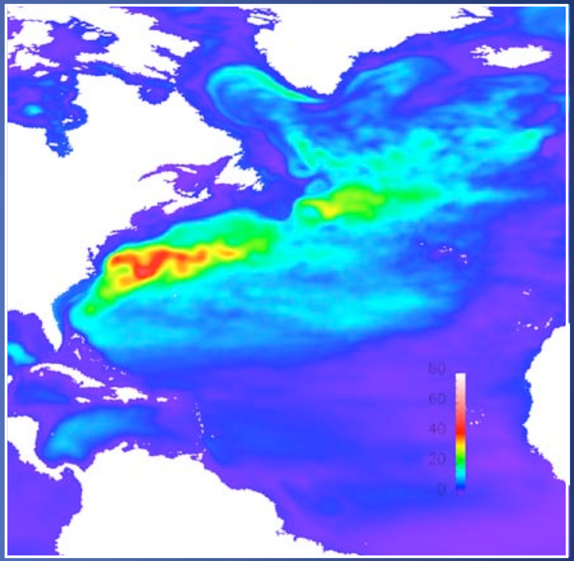
Observations: AVISO



Traditional Approach:
Global, quasi-uniform mesh
15 km resolution everywhere



New Approach:
Global, variable-resolution mesh
15 km in North Atlantic, 75 km elsewhere



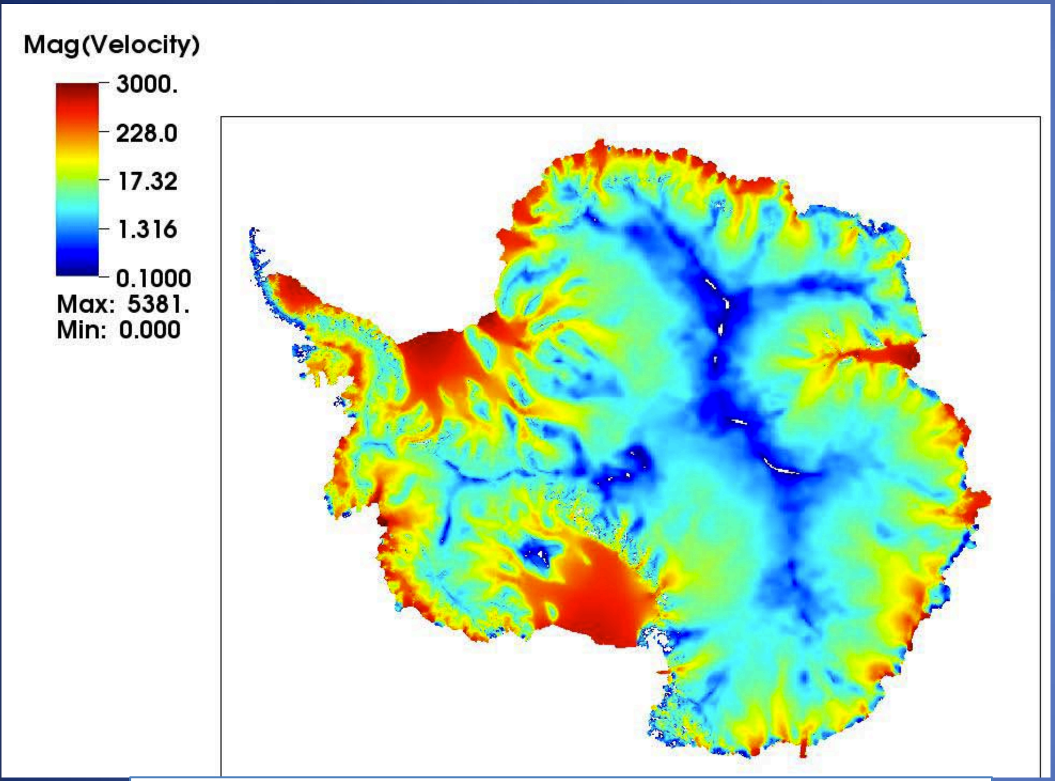
Figures show sea-surface height RMS which is a proxy for the amplitude of mesoscale ocean eddies.

The mesoscale eddies in the North Atlantic are simulated as well on the variable resolution mesh as on the uniform-resolution mesh, but at only 15% the cost.

Slide courtesy of Todd Ringler

Marika Holland
mholland@ucar.edu

Community Ice Sheet Model (CISM)



Antarctic ice speed, BISICLES model (red = fast flow)

- Now testing scalable dynamical cores with higher-order ice flow
  - –SEACISM dycore with Trilinos solvers
  - –BISICLES dycore with adaptive mesh refinement
  - –To be included in CISM 2.0, CESM 1.1

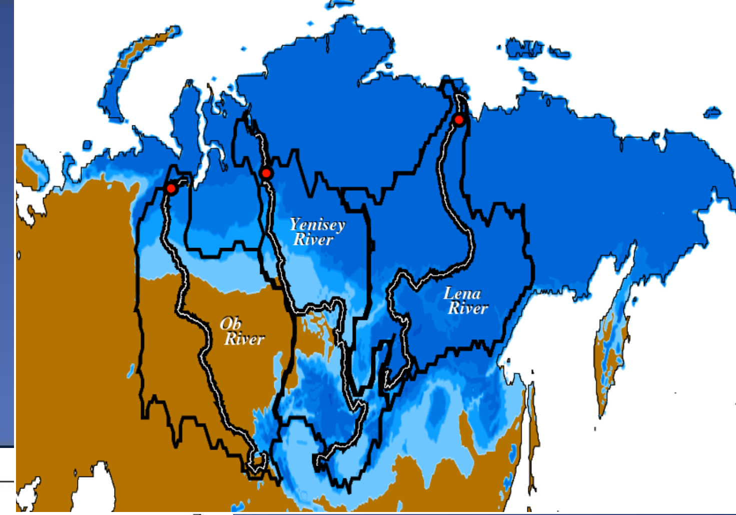
Slide courtesy of Bill Lipscomb

Marika Holland
mholland@ucar.edu

Cold region hydrology

In Control, water permeates icy soils too easily causing poorly simulated discharge in permafrost basins

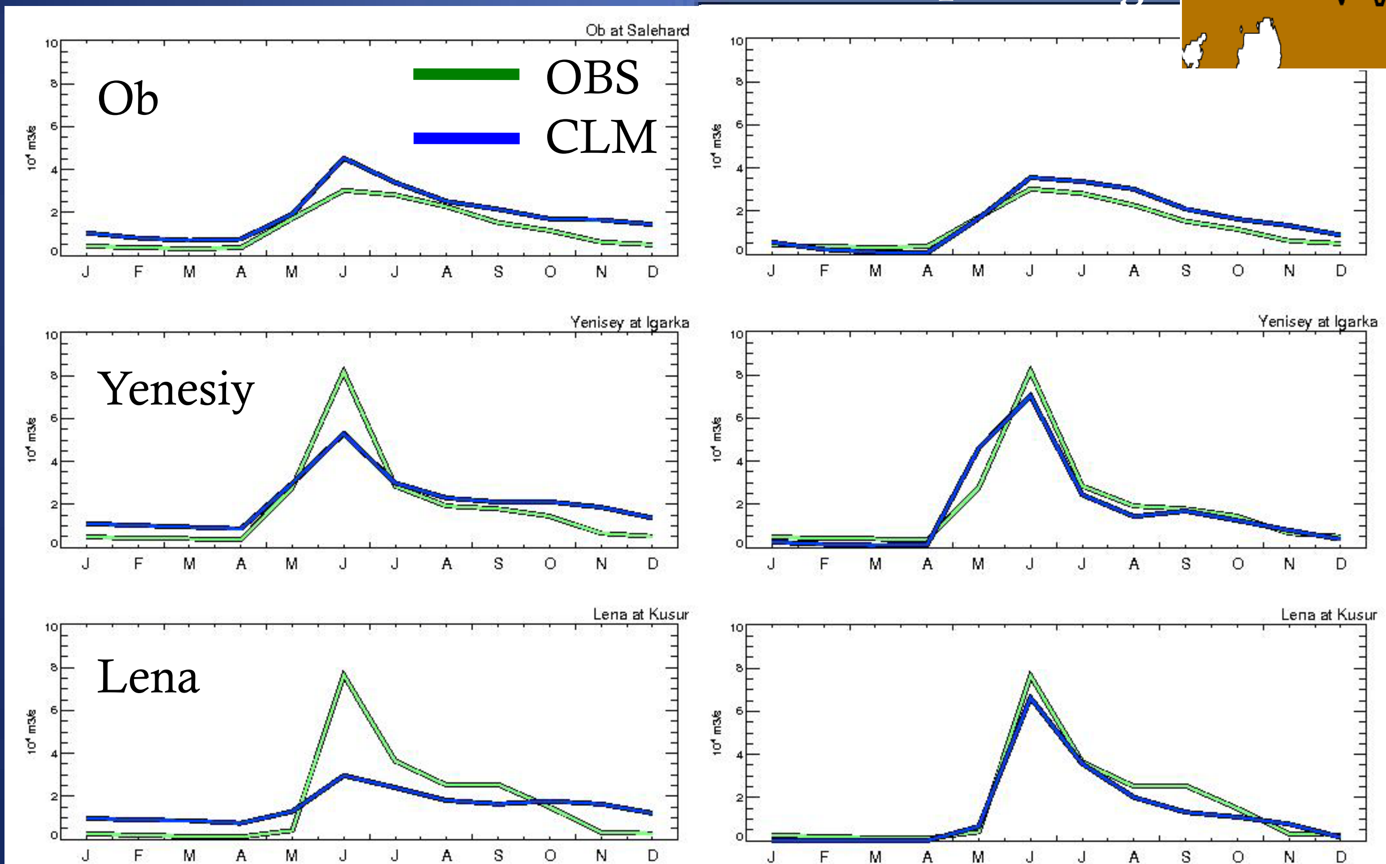
Results: Good hydrographs for both permafrost basins and non-permafrost basins; better active layer hydrology and veg?



Control

Ice Impedance

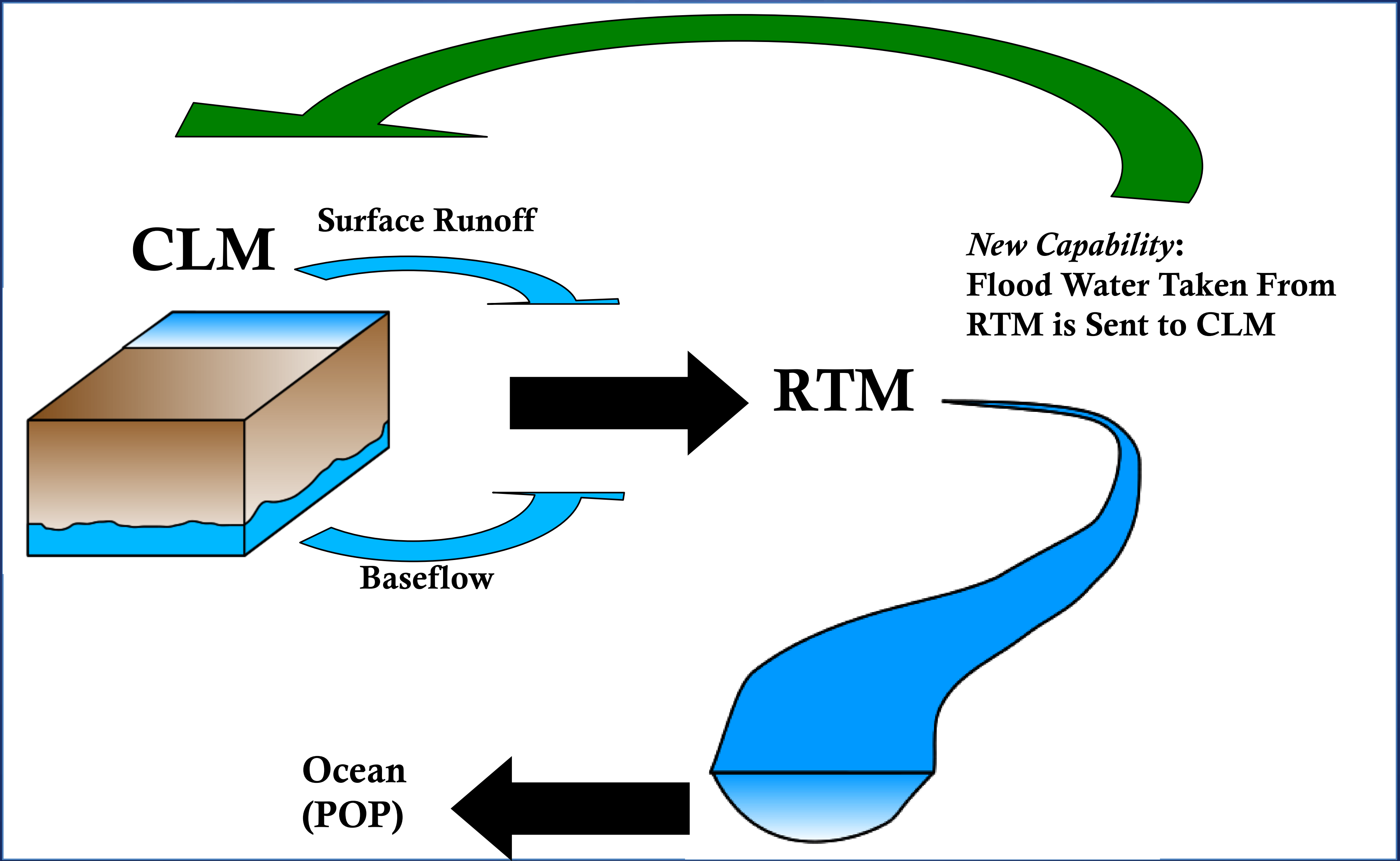
Ice Impedance + Wetlands/Flooding



Swenson and Lawrence, in prep

Marika Holland
mholland@ucar.edu

Adding Flooding Capability / 2-way CLM-RTM interactions



Slide courtesy of Dave Lawrence

Marika Holland
mholland@ucar.edu

Development of an Isotope-Enabled CESM

Simulating Stable Water Isotopes in the Climate System

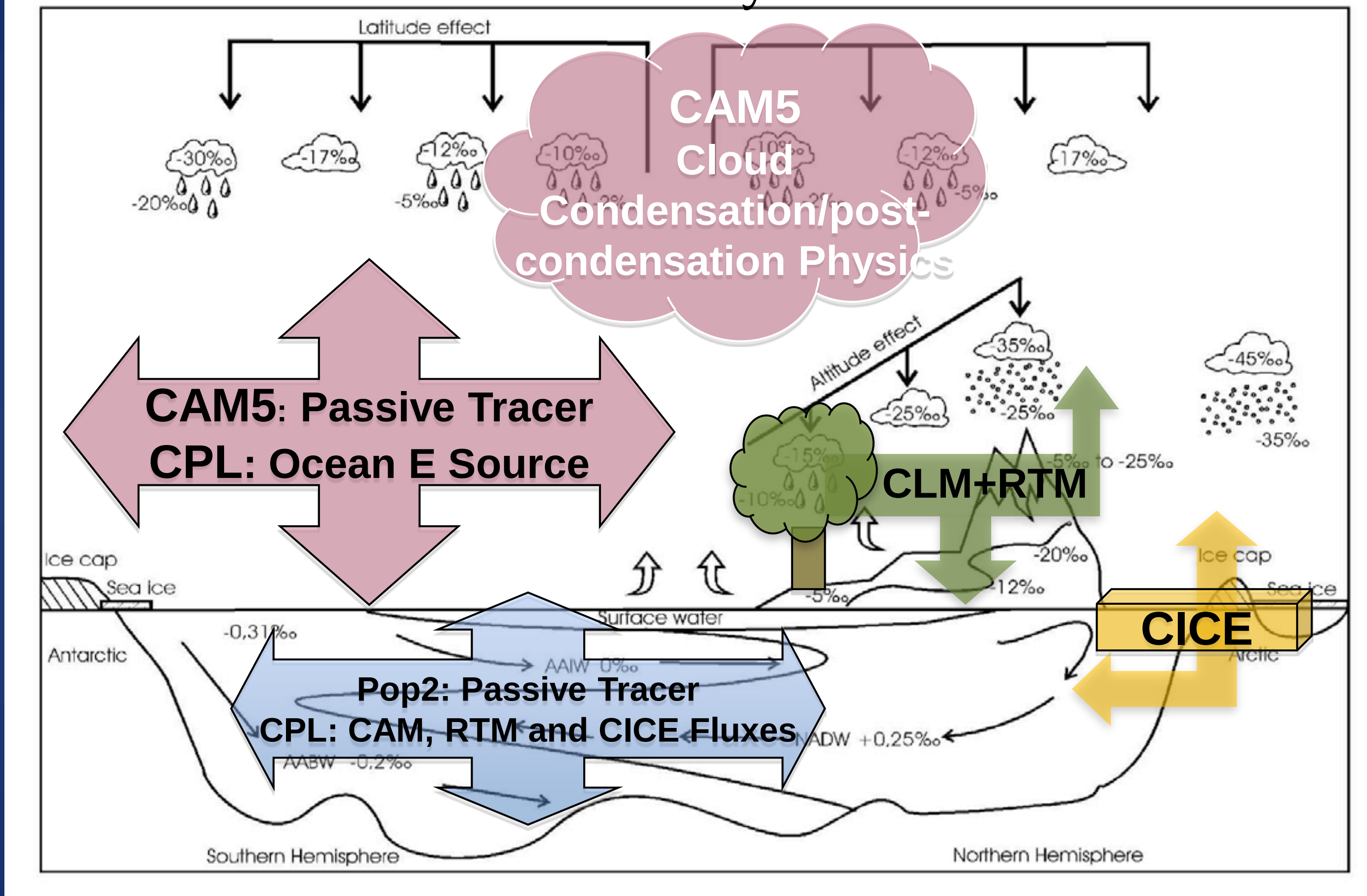


Figure adapted from Paul, A. et al. 1999: Simulation of Water Isotopes in a Global Ocean Model, in *Use of Proxies in Paleoclimatology: Examples from the So. Atlantic,* Fischer G. and W. Wefer, eds., Springer-Verlag, 655-686.

Community effort partnering NCAR, U. Wisc, U. CO, U. Bern, DOE LBL

Slide courtesy of B. Otto-Bliesner

Marika Holland
mholland@ucar.edu

And More…

All component models incorporating improved parameterizations and processes

Marika Holland
mholland@ucar.edu

In summary:

- CESM is a flexible, extensible and well supported community tool
- CESM applications continue to increase
- Numerous CESM simulations are currently available through CMIP5 for analysis
- Model developments and improvements are ongoing

NCAR is sponsored by the National Science Foundation

Marika Holland
mholland@ucar.edu

Questions?

Marika Holland
mholland@ucar.edu

Extra Slides

Marika Holland
mholland@ucar.edu

Atmospheric Model

- Solves equations describing the thermodynamics and fluid dynamics of an ideal gas
- Atmospheric state described by temperature, pressure, humidity, winds, and water and ice condensate in clouds
- Coordinate system in which the Earth's surface is a coordinate surface
- Radiative-transfer code computes the absorption and emission of radiant energy
- Subgrid-scale parameterizations simulate unresolved processes

Marika Holland
mholland@ucar.edu

Ocean Model

- Solve equations for incompressible fluid flow
- Includes computation of circulation, temperature, salinity, density
- Complex three-dimensional boundary due to continents, enclosed basins, narrow straits
- Equation of state is an empirical function of T,S,p
- Eddies not resolved so mixing must be parameterized.
- Other mixing processes that may be important in the ocean include tidal mixing and turbulence generated by interactions with the ocean's bottom

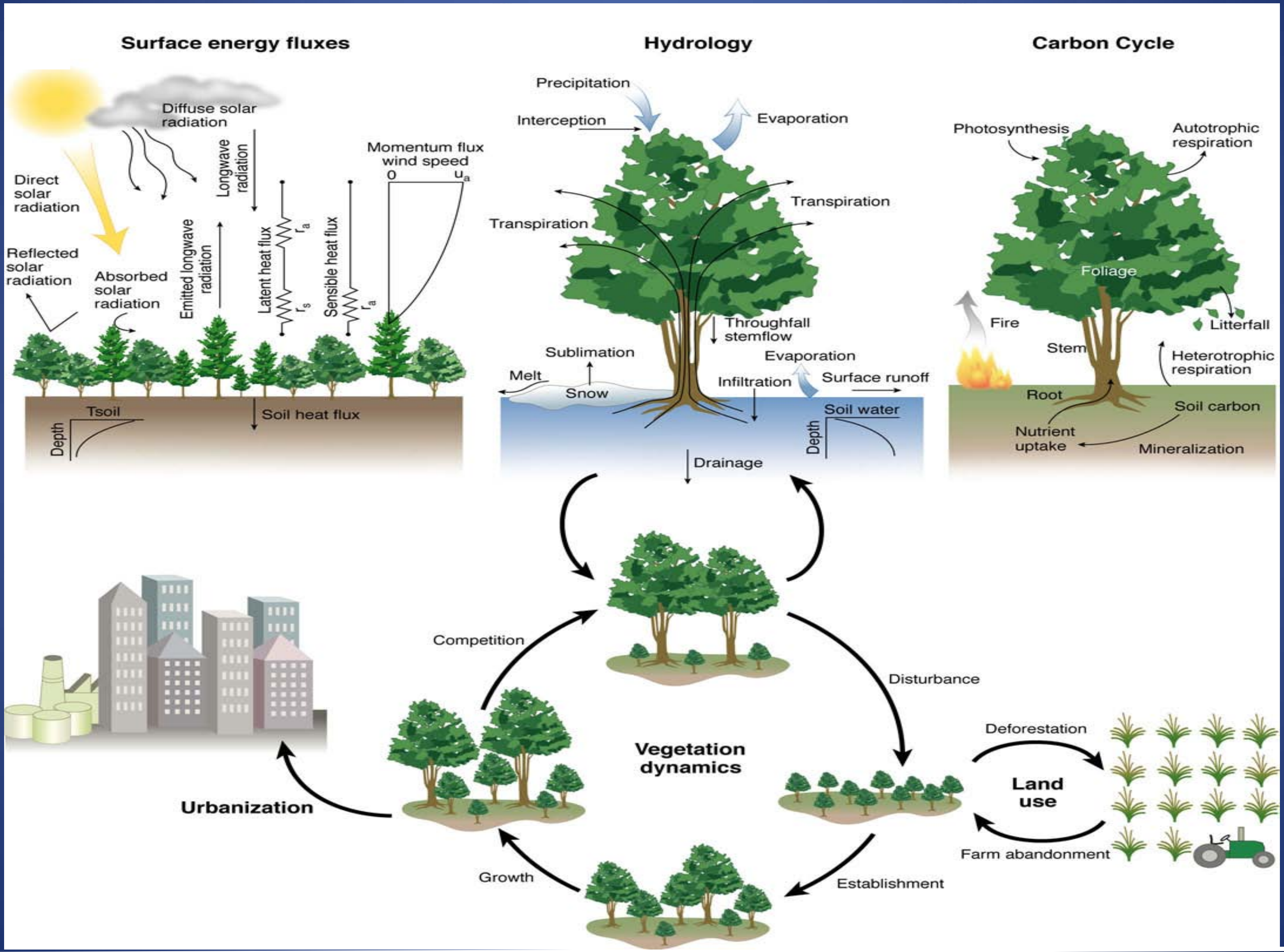
Marika Holland
mholland@ucar.edu

Sea Ice Model

- Solves for the Ice Thermodynamics
  - Including vertical heat transfer and temperature profile
  - Vertical and Lateral sea ice melt and/or growth
- Solves for Ice Dynamics
  - Assuming that sea ice freely diverges but resists convergence and shear
- Includes a sub-gridscale ice thickness distribution parameterization to account for the high spatial variability in sea ice

Marika Holland
mholland@ucar.edu

Land Model



Marika Holland
mholland@ucar.edu